AFFTC

A LIMITED FLIGHT TEST INVESTIGATION OF PILOT-INDUCED OSCILLATION DUE TO ELEVATOR RATE LIMITING (HAVE LIMITS)

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FINAL REPORT

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The report presents the results of a limited flight test investigation of pilot-induced oscillation (PIO) due to elevator rate limiting. The objective of this effort was to gather in-flight and ground-based simulation data on longitudinal PIO tendencies due to elevator rate limiting. Preliminary, ground-based simulation was conducted at the USAF Test Pilot School (TPS) from 1 March to 9 April 1997. Nine sorties, totaling 12.8 flight hours, were flown in the NT-33A aircraft. Additional ground-based simulation was conducted at the Flight Dynamics Directorate, Wright-Patterson AFB, Ohio, on 25 April 1997. The USAF TPS was the responsible test organization.

14. SUBJECT TERMS

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PREFACE

This report presents the results of a limited flight test investigation of pilot-induced oscillation (PIO) due to elevator rate limiting. The objective of this effort was to gather in-flight and ground-based simulation data on longitudinal PIO tendencies due to elevator rate limiting. The USAF Test Pilot School (TPS) was the responsible test organization.

Descriptions of the configurations, instrumentation, test methods, and test procedures are provided within the test and evaluation section of this report. Results, data products, data analysis, and the flight tests are also discussed. The test program was requested and funded by the Flight Dynamics Directorate of Wright Laboratory, Wright-Patterson AFB, Ohio, and directed by the Commandant, USAF TPS, under job order number M96J0200.

Special thanks are due to the Calspan flight and ground crew including Mssrs. Lou Knotts, safety pilot; Mike Sears, crew chief; and Jim Priest, engineer. Additionally, Mssrs. Dave Mitchell and Roger Hoh of Hoh Aeronautics aided significantly in the development of the test plan, test matrix, and analyses of the results.

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EXECUTIVE SUMMARY

This report presents the results of a limited flight test investigation of pilot-induced oscillation (PIO) due to elevator rate limiting. The objective of this effort was to gather in-flight and ground-based simulation data on longitudinal PIO tendencies due to elevator rate limiting. This data were incorporated into the PIO database at Wright Laboratory to improve ground-based simulation. The USAF Test Pilot School (TPS) was the responsible test organization.

Preliminary ground-based simulation was conducted at the USAF TPS from 1 March to 9 April 1997. Flight testing was conducted using the NT-33A in-flight simulator aircraft at the Air Force Flight Test Center, Edwards AFB, California, from 11 to 22 April 1997. Nine sorties totaling 12.8 flight hours were flown in the NT-33A aircraft. Additional ground-based simulation was conducted at the Flight Dynamics Directorate of Wright Laboratory, Wright-Patterson AFB, Ohio, on 25 April 1997. The test program was requested and funded by the Flight Dynamics Directorate of Wright Laboratory, Wright-Patterson AFB, Ohio, and directed by the Commandant, USAF TPS, under job order number M96J0200.

All test objectives were met. Three aircraft configurations were verified and then flown on the NT-33A and the ground-based Large Amplitude Multimode Aerospace Research Simulator (LAMARS) using two head-up display tracking tasks and seven elevator rate limits. The configurations were represented by three different longitudinal dynamics flight control implementations. In total, 36 test conditions were flown by at least 2 pilots in the NT-33A aircraft, while 27 test conditions were flown by at least 2 pilots in the LAMARS. Comparisons of the LAMARS to the NT-33A aircraft assume that the LAMARS was representative of the NT-33A aircraft; however, an issue concerning the simulation matching NT-33A flight test results was not resolved. A database of pilot comments and ratings, as well as time histories, was generated For both in-flight and ground-based simulation.

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INTRODUCTION

BACKGROUND

According to a report from the National Research Council, the most important design tool for avoiding, discovering, and correcting pilot induced oscillation (PIO) is simulation and analysis to seek out unexpected trigger events and interactions (Reference 1). Unfortunately, PIO is difficult to detect in a simulator. The National Research Council report (Reference 1) goes on to say that almost all new fly-by-wire-equipped aircraft have exhibited PIO events at some time during development. The PIO events usually occur when the pilot is engaged in demanding tasks, working hard to precisely control the aircraft.

The Flight Dynamics Directorate of Wright Laboratory has been researching the ability to predict PIO tendencies on ground-based simulators (Reference 2). Past work utilized the 1985 HAVE PIO database which examined PIO due to linear causes in the landing phase (Reference 3). This research aided in the development of methods and techniques to better correlate simulator predictions with in-flight results. The Flight Dynamics Directorate wished to expand the PIO database to include nonlinear effects such as elevator rate limiting at multiple flight phases. The 1996 HAVE GRIP flight test program examined PIO due to elevator rate limiting in the landing phase using the Calspan variable stability Learjet (Reference 4). Conclusions from the HAVE GRIP program helped define the test condition matrix for this test program.

The objective of a limited flight test investigation of PIO due to elevator rate limiting (HAVE LIMITS) was to gather in-flight and ground-based simulation data on longitudinal PIO tendencies due to elevator rate limiting. The USAF TPS was the responsible test organization. Differences from the HAVE GRIP flight test program include multiple aircraft configurations, different tasks, and a different flight phase (cruise). Also, HAVE GRIP did not have the pilots fly any ground-based simulators.

The NT-33A aircraft was used during this test program with three different longitudinal aircraft dynamics. Several handling qualities and PIO criteria were employed to make estimates of the expected flight results. None of these criteria explicitly addresses the effect of rate limiting, however. The linear short-period approximations for the three non-rate-limited configurations were used. Rate limiting introduces a significant phase lag in airplane response, so it was assumed that the primary effect of rate limiting would be an effective increase in time delay.

Figures A7 through A10 show predicted handling qualities and susceptibility to PIO for the three configurations without rate limiting. Configuration 2D was expected to be Level 1 (the Neal-Smith criteria suggested it might be Level 2). Configuration 2DU, augmentation active, was also expected to be Level 1 (Level 2 on Neal-Smith), though an additional pitch rate overshoot criterion developed by Hoh Aeronautics, not shown in Figures A7 through A10, suggested Level 2 flying qualities would be expected. Finally, configuration 2P was expected to be Level 2 and possibly exhibit PIO tendencies.

With the added time delay resulting from rate limiting, configuration 2D, with its very high bandwidth, was expected to be relatively resistant to PIO. With very low rate limits, it was likely that this configuration would become unflyable due to a lack of airplane response before it would develop sustained PIO. Configuration 2P was expected to show PIO with rate limiting. For configuration 2DU, the effect of rate limiting was expected to be sudden and dramatic; in the absence of rate limiting, it was expected to be good, and become strongly divergent when rate limiting was reached. The terminology used for the three aircraft models is provided in Table 1.

The NT-33A aircraft was flown using two head-up display (HUD) tracking tasks designed to make the pilot increase gain to precisely control the aircraft. The HUD tracking tasks were also programmed and displayed in the two ground-based simulators. Seven different elevator rate limits were used in both simulation and flight.

Table 1
DEFINITION OF THE THREE AIRCRAFT MODELS

Aircraft Models	Description of Simulated Aircraft Longitudinal Dynamics
2D	Tested Good Aircraft, Level 1 Handling Qualities
2P	2D with Additional Phase Lag
2DU	Predicted Unstable Aircraft Augmented to Level 1 Handling Qualities

PROGRAM CHRONOLOGY

This test program used the paradigm of predict-test-compare. Along with analytical predictions, pilots practiced the HUD tracking tasks beginning in March 1997, on the USAF TPS ground-based simulator developed by High Plains Engineering. During this simulation, various elevator rate limits were considered and established for use on the NT-33A. Flight tests and ground model verification were conducted using the NT-33A, at the Air Force Flight Test Center (AFFTC) Edwards AFB, California, from 11 to 22 April 1997. Nine sorties totaling 12.8 flight hours were flown in the NT-33A. Comparative testing was completed on 25 April 1997, when the evaluation pilots flew the majority of the configurations flown during flight test, on the ground-based Large Amplitude Multimode Aerospace Research Simulator (LAMARS) with motion. The simulator is located at the Flight Dynamics Directorate of Wright Laboratory, Wright-Patterson AFB, Ohio.

TEST ITEM DESCRIPTION

The test items were three longitudinal aircraft models listed in Appendix A. The lateral-directional model used for the test program was the same for all three configurations and is also listed in Appendix A. The same aircraft dynamics flown in the NT-33A aircraft were mathematically modeled and flown in the USAF TPS simulator and LAMARS with motion. Specific descriptions of each of these test assets are listed in Appendix A.

TEST OBJECTIVES

The overall test objective was to gather in-flight and ground-based simulation data on longitudinal PIO tendencies due to elevator rate limiting. To meet this overall objective, data were gathered using aircraft dynamics, a range of elevator rate limits, and two HUD tracking tasks as shown in Figure 1. During an evaluation, the pilot flew one of the two HUD tracking tasks on either the ground-based or in-flight simulator with a particular set of aircraft dynamics and one of the elevator rate limits. Each evaluation generated a database of pilot ratings, comments, and time-history data.

The following four specific test objectives were developed to meet the overall objective:

1. Verify the aircraft models in Appendix A were correctly implemented on the NT-33A aircraft,

2. Determine a range of elevator rate limits for use on the NT-33A aircraft during flight test,

3. Gather in-flight data for the test conditions in Appendix A, and

4. Gather ground-based simulation data using LAMARS for the test conditions in Appendix A for comparison with in-flight data.

All test objectives were met.

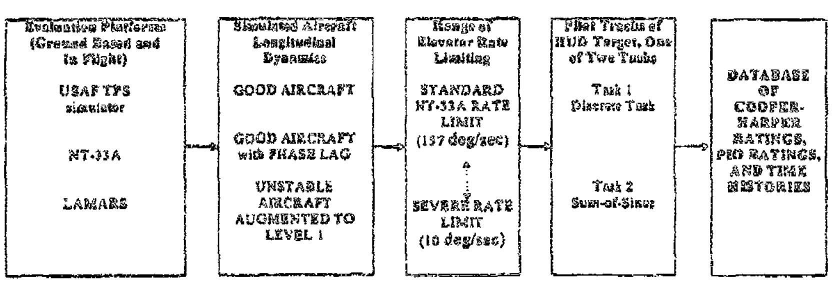


Figure 1 Test Program Concept

TEST AND EVALUATION

GENERAL

All test objectives were met. The preliminary simulation was conducted in the USAF TPS simulator to practice mission conduct and determine a range of possible elevator rate limits. Based on USAF TPS simulation results, a range of elevator rate limits was given to Calspan prior to their checkout and verification flights in Buffalo, New York, on 24 and 27 March 1997. Calspan verified the aircraft models, the HUD tracking tasks, and a range of rate limits for use in flight tests at the AFFTC, Edwards AFB, California, from 11 to 22 April 1997. During flight test, nine sorties totaling 12.8 flight hours (three sorties per evaluation pilot) were flown at Edwards AFB, in the NT-33A aircraft. It was assumed that ground-based simulation in LAMARS was done with the same rate limits, aircraft models, and HUD tracking tasks as those used in the NT-33A test flights. Figure 2 provides an overview of the test program flow.

All testing was conducted using the aircraft models, rate limits, and tracking tasks described in Appendix A. The aerodynamic models were point designs for 250 knots and 10,000 feet pressure altitude. Flight test briefings, in-flight execution, and postflight debriefings were completed in accordance with (IAW) the procedures in Appendix F. All NT-33A flight testing was accomplished in the cruise configuration (gear/flaps/speedbrake retracted). Ground-based simulation in LAMARS was done after flight testing so the exact test conditions tested in-flight were simulated. Requirements for the procedural flow of the test plan are detailed in the Requirements Traceability Matrix (Appendix E) and the Project HAVE LIMITS test plan (Reference 5). The HUD tracking tasks flown in the USAF TPS simulator and LAMARS were assumed to be the same as the NT-33A aircraft as described in Appendix A.

VERIFICATION OF AIRCRAFT MODELS

Methods and Conditions:

In accordance with the paradigm of predict-test-compare, the following two analytical methods were used to verify the three aircraft models:

1. Pitch-step response comparison with MATLAB® time-domain predictions, and

2. Frequency response analysis (FRA) with lower order equivalent system (LOES).

During the first checkout flight in Buffalo, New York, the Calspan pilot initiated programmed pitch-step inputs for the three aircraft models defined in Appendix A. The Calspan pilot also conducted a 40-second manual pitch frequency sweep of the three aircraft models. The standard NT-33A aircraft elevator rate limit of 157 degrees per second was used for model verification. The time-domain data, defined in Appendix D, were collected by Calspan and provided to USAF TPS for analysis. Calspan also provided FRA with a LOES estimation for each aircraft response model based on their own criterion which was different from the one suggested in MIL-STD-1797A (Reference 6). Time-domain data from the Calspan checkout flights were compared against preflight predictions modeled in MATLAB® version 4.2C. Final data products consist of time-domain comparisons of pitch response to predictions, Bode plot comparisons of aircraft dynamics to the LOES estimation, and a table comparing the LOES-estimated second order aircraft dynamics to the requested aircraft dynamics. Successful aircraft response verification was defined as Flight Dynamics Directorate acceptance of the three aircraft models based on quick-look data products provided prior to flight test at Edwards AFB.

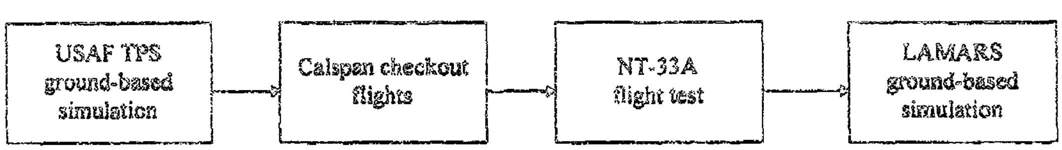


Figure 2 Test Program Flow

Results and Analyses:

The thr..e aircraft models, defined in Appendix A, were successfully verified. The NT-33A model validation flight test was conducted by Calspan on 27 March 1997. The flight test and subsequent quick-look analyses were completed prior to the beginning of testing at Edwards AFB on 11 April 1997. As stated in the procedures, data products included both time-domain and FRA comparisons. Time-domain step response results are presented in Figure B1. The three time-domain pitch response figures compare flight test results to requested aircraft dynamic response. Frequency-domain results are also presented in Figures B2, B3, and B4 for the three aircraft models.

Calspan's criterion improved the accuracy of the LOES match with respect to the FRA flight test data at low frequency (Figures B2, B3, and B4).

Frequency-domain validation of the three aircraft models was based on the LOES estimation of aircraft response compared to the requested aircraft dynamics. Percent differences are listed in Table 2.

The most significant difference was the 2DU dynamic response (both short period damping [ζ_{sp}] and natural frequency [$\omega_{n_{sp}}$]). In both the time-domain (Figure B1) and the frequency-domain (Figure B4), 2DU flight test results did not provide an exact match to the requested dynamics. The time- and frequency-domain comparison of 2DU was provided to the Flight Dynamics Directorate prior to flight test. While the Flight Dynamics Directorate acknowledged the differences between 2D and 2DU, they approved the three aircraft dynamics as satisfactory for the purpose of this elevator rate limit investigation.

DETERMINATION OF ELEVATOR RATE LIMIT RANGE

Methods and Conditions:

The range of elevator rate limits to be used in the actual flight test program was determined through a three-step process.

1. The USAF TPS simulator was used to perform an elevator rate limit investigation to recommend a range of elevator rate limits to Calspan prior to checkout flights in Buffalo, New York. The investigation consisted of pilots flying the 2D aircraft model with the sum-of-sines and discrete tracking tasks with various elevator rate limits. The evaluation criteria for the investigation was the percentage of time on the simulated elevator rate limit. The success criteria for the USAF TPS simulator was a range of elevator rate limits that provided different percentages of time (<5 to >20 percent) on the simulated elevator rate limit.

Table 2
COMPARISON OF LOWER ORDER EQUIVALENT SYSTEM SECOND ORDER AIRCRAFT RESPONSE WITH REQUESTED AIRCRAFT DYNAMICS

Model	Parameter	Flight Test Lower Order Equivalent System	Requested Aircraft Dynamics	Difference (pct) $\frac{(test - request)}{request} \times 100$ pct
2D	ζ_{sp}	0.740	0.7	+5.71
	$\omega_{n_{sp}}$ (rad/sec)	4.863	4.9	-0.76
	$T_{\theta 2}$	0.837	0.8	+4.63
2P	ζ_{sp}	0.740	0.7	+5.71
	$\omega_{n_{sp}}$ (rad/sec)	4.863	4.9	-0.76
	$T_{\theta 2}$	0.837	0.8	+4.63
2DU	ζ_{sp}	0.640	0.7	-8.57
	$\omega_{n_{sp}}$ (rad/sec)	5.166	4.9	+5.43
	$T_{\theta 2}$	0.837	0.8	+4.63

Notes: 1. ζ_{sp} - short period damping ratio
2. $\omega_{n_{sp}}$ - short period natural frequency
3. $T_{\theta 2}$ - high frequency pitch attitude zero

2. During checkout flights in Buffalo, New York, Calspan pilots flew different elevator rate limits within the range determined in the USAF TPS simulator using the same 2D aircraft model and tasks. Calspan then recommended three primary and four back-up rate limits for the test program. Calspan based their recommendation on achieving a range of values for percentage of time on the elevator rate limit.

3. During flight test sortie 1, an evaluation of the Calspan recommended elevator rate limits was completed. After the flight, data were evaluated from each test point. Evaluation criteria were a quick-look analysis of Cooper-Harper (CH) and PIO ratings. The success criteria was a qualitative comparison of flight test results and preflight predictions.

Results and Analyses:

Based on the USAF TPS ground-based simulation, elevator rate limits of 10, 20, 30, 40, 50, and 60 degrees per second were recommended to Calspan prior to their checkout flights. Calspan then flew with these elevator rate limits on 24 and 27 March 1997, and recommended three primary and four secondary values which are listed in Table 3.

Table 3
CALSPAN RECOMMENDED
ELEVATOR RATE LIMITS

Primary Elevator Rate Limits (deg/sec)	Secondary Elevator Rate Limits (deg/sec)
20	10
40	30
50	60
---	157

Note: '---' - not applicable

The three primary elevator rate limits were flown and qualitatively evaluated by USAF TPS and Calspan. The primary elevator rate limits produced a full range of CH and PIO ratings. Thirteen evaluations were made during the first sortie (eight to nine evaluations were expected). Due to this increased test point efficiency, the test team determined the secondary elevator rate limits could also be evaluated in sorties 2 through 9.

IN-FLIGHT DATA COLLECTION

Methods and Conditions:

Each test condition in Appendix A was flown by at least two pilots. If the CH ratings differed by more than two for any test condition, that test condition was flown at least three times. Pretest briefing, test execution procedures, and debriefing requirements are listed in Appendix F.

Pilot comments were recorded on audio and HUD video referencing the pilot comment card in Appendix D for each test condition flown. The CH and PIO ratings (using the respective scales in Appendix D) were given by each pilot for each test condition flown. Time histories of the parameters listed in Appendix D were recorded for every test condition. After each sortie, the evaluation pilot transcribed his comments while reviewing the HUD audio/video recording.

All test points in the test condition matrix in Appendix A were flown at 250 ±20 knots at 10,000 ±1,000 feet pressure altitude. The safety pilot controlled the throttle to maintain airspeed. To ensure objectivity, the evaluation pilot did not know which test point was being evaluated and was allowed to repeat any point as necessary.

Results and Analyses:

Appendix C contains an overall evaluation of each test condition, pilot comments, and sample time histories. The 36 different test conditions flown on the NT-33A aircraft are listed in Table 4. Experiment number, aircraft configuration, task, rate limit, CH, and PIO ratings are listed. Pilot ratings by different pilots are separated by "‖". Multiple ratings by the same pilot are separated by "/". The order of pilot ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3. If a given pilot did not fly a test condition, a "-" is used.

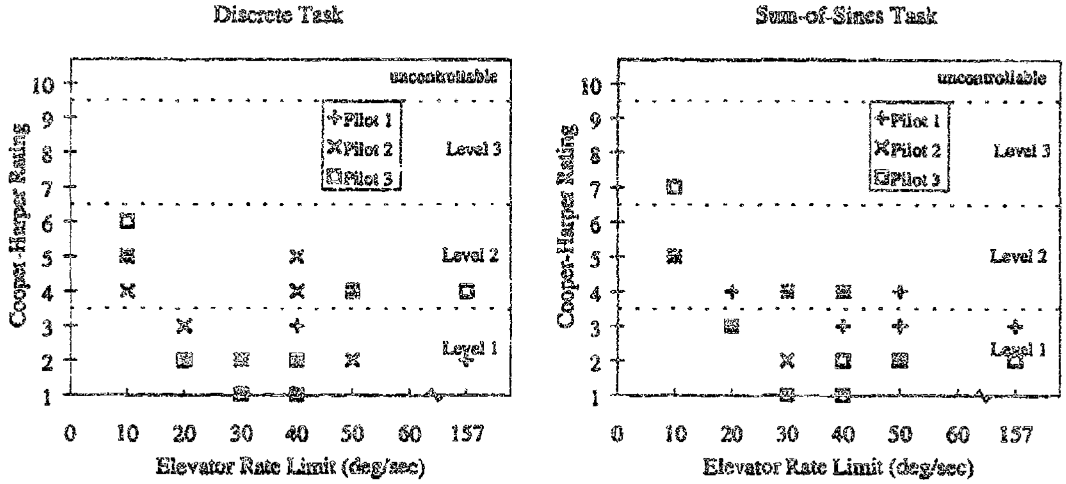
Figures 3 and 4 are graphical representations of the CH and PIO ratings for each test condition evaluated in flight. Each of the six subplots in Figures 3 and 4 shows the ratings for a particular aircraft configuration and task over the range of rate limits and pilots (e.g., 2D, discrete task, rate limits 10 to 157 degrees per second, all three pilots). In the figures, task is broken out by subplot

Table 4
PILOT RATINGS FOR NT-33A FLIGHT TEST PROGRAM
(11 THROUGH 22 APRIL 1997)[1]

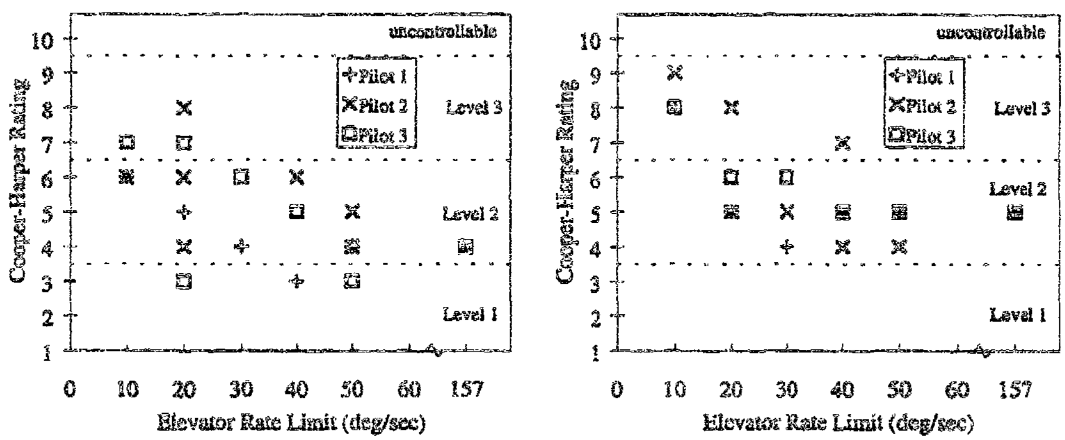
Exp	A/C	Task	RL	CHR	PIOR
40	2D	discrete	10	5‖5/4‖6	3‖3/2‖3
41	2D	discrete	20	2‖3‖2	2‖2‖2
42	2D	discrete	30	2‖2‖1	2‖1‖1
43	2D	discrete	40	3‖5/2/4‖1/2	2‖3/1/2‖1/2
44	2D	discrete	50	4‖2‖4	2‖1‖2
46	2D	discrete	157	2‖-‖4	2‖-‖2
47	2D	SOS	10	5‖5‖7	3‖3‖4
48	2D	SOS	20	4‖3‖3	3‖2‖2
49	2D	SOS	30	4‖4/2‖1	3‖2/1‖1
50	2D	SOS	40	4/3‖4‖1/2/1	3/2‖3‖1/2/1
51	2D	SOS	50	4/3‖2‖2	2/2‖1‖1
53	2D	SOS	157	3‖-‖2	2‖-‖1
54	2P	discrete	10	6‖6‖7	3‖5‖3
55	2P	discrete	20	5‖4/6/4/8‖7/3	4‖3/4/3/4‖4/1
56	2P	discrete	30	4‖-‖6	3‖-‖3
57	2P	discrete	40	3‖6‖5/5	2‖4‖3/3
58	2P	discrete	50	4‖5/4‖3	2‖3/3‖2
60	2P	discrete	157	4‖-‖4	2‖-‖2
61	2P	SOS	10	8‖9‖8	4‖4‖4
62	2P	SOS	20	5‖8/5/8‖6	4‖5/4/5‖4
63	2P	SOS	30	4‖5‖6	3‖3‖3
64	2P	SOS	40	5‖7/4/5‖5	4‖4/3/3‖3
65	2P	SOS	50	5‖4‖5	3‖2‖3
67	2P	SOS	157	5‖-‖5	3‖-‖3
69	2DU	discrete	20	10‖10‖10	6‖6‖5
70	2DU	discrete	30	9‖-‖10	5‖-‖5
71	2DU	discrete	40	10‖10‖10	5‖6‖5
72	2DU	discrete	50	5/9‖10‖10	4/4‖5‖5
73	2DU	discrete	60	8‖4/3‖10/10	4‖3/2‖5/5
74	2DU	discrete	157	-‖2‖5/4	-‖2‖3/2
76	2DU	SOS	20	10‖10‖10	6‖6‖6
77	2DU	SOS	30	8/3‖2‖9/8	4/2‖1‖4/3
78	2DU	SOS	40	5‖3/4‖6	3‖2/3‖4
79	2DU	SOS	50	5‖4‖6	4‖3‖3
80	2DU	SOS	60	3‖3/3‖5	2‖2/2‖3
81	2DU	SOS	157	3‖-‖3	2‖-‖2

Notes:
1. Exp - Calspan-designated experiment numbers which appear on all head-up display video tapes
2. RL - elevator rate limit in degrees per second
3. PIOR - pilot-induced oscillation rating
4. A/C - aircraft configuration
5. SOS - sum-of-sines
6. CHR - Cooper-Harper rating
7. "–" - pilot did not fly the test condition

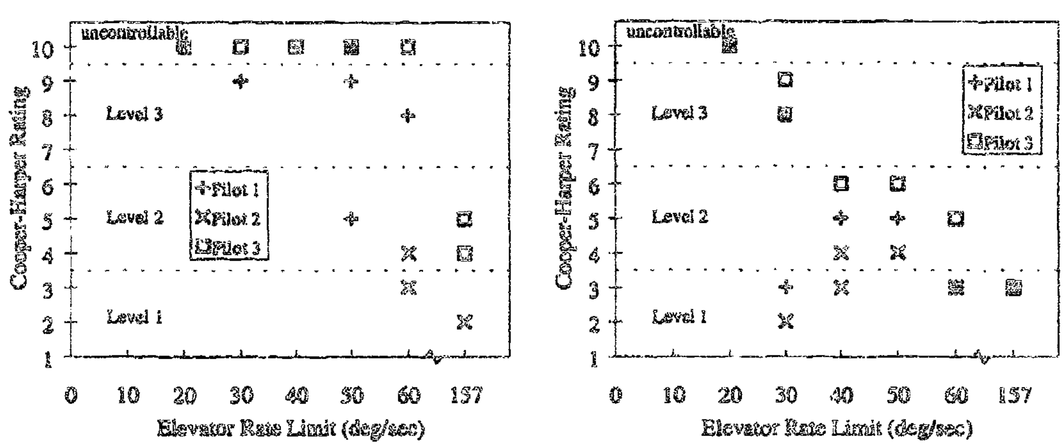
[1]Multiple ratings by same pilot separated by "/". Order of pilot ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.



a. Aircraft Configuration 2D



b. Aircraft Configuration 2P



c. Aircraft Configuration 2DU

Figure 3 Cooper-Harper Ratings for NT-33A Flight Test Program (11 through 22 April 1997)

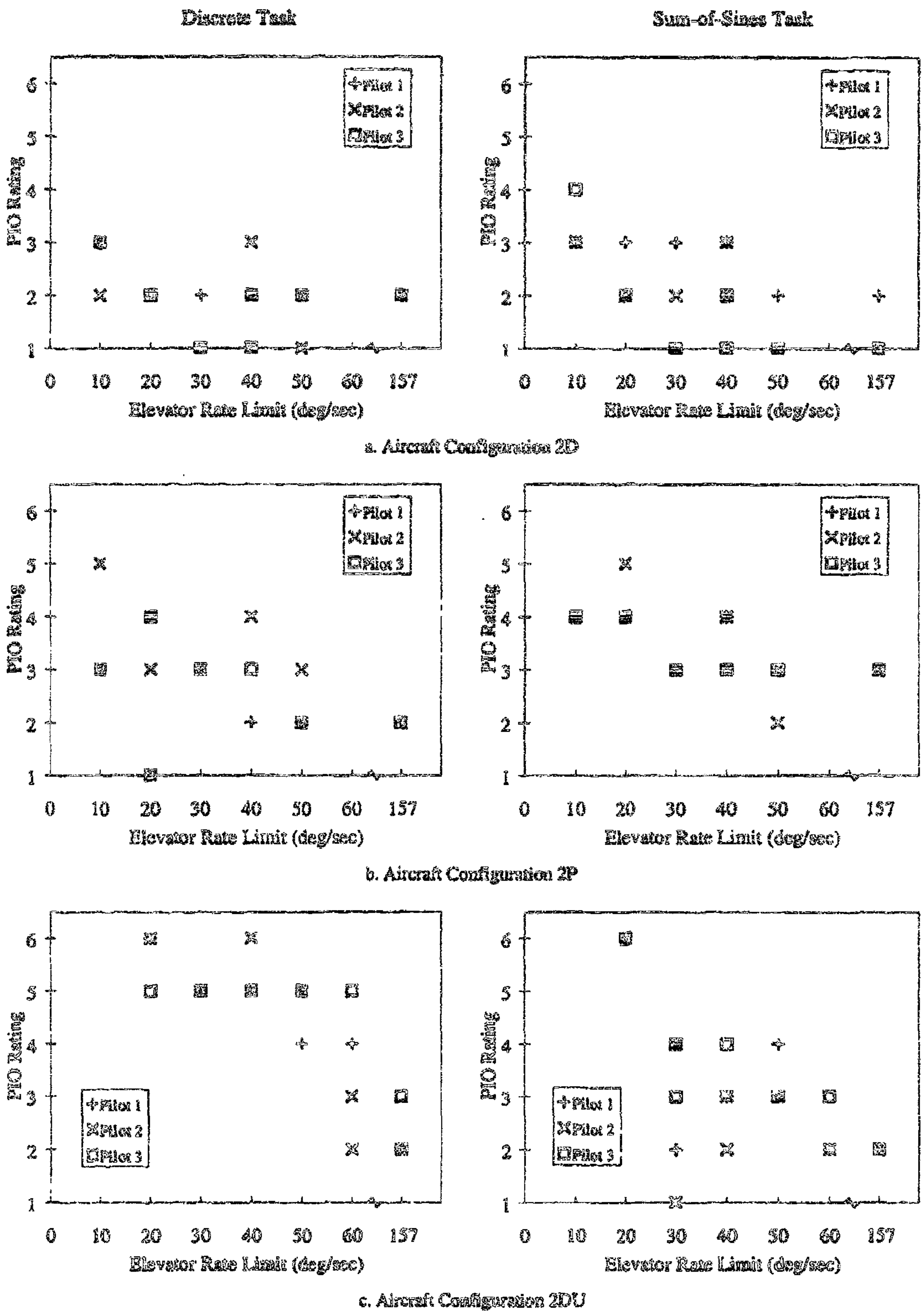


Figure 4 Pilot-Induced Oscillation Ratings for NT-33A Flight Test Program (11 through 22 April 1997)

column, aircraft configuration by subplot row. Rate limit is varied over the x-axis in each plot, and pilots are identified by different symbols. The following analysis of rating trends is broken down by aircraft configuration.

Overall, configuration 2D was evaluated as Level 1 with no PIO tendency for elevator rate limits of 20 degrees per second and above. Pilots commented that configuration 2D felt "springy" at elevator rate limits of 50 degrees per second and above. Consequently, lower values (30 to 40 degrees per second) tended to "smooth" the aircraft response resulting in better ratings. Decreasing the elevator rate limit to 10 degrees per second degraded ratings and resulted in one PIO. The difference between the two tasks did not appear to affect pilot ratings.

Overall, configuration 2P was evaluated as Level 2 for elevator rate limits of 20 degrees per second and above. Generally, pilot ratings were higher for the sum-of-sines than the discrete task. Configuration 2P had added phase lag which was a function of frequency. The sum-of-sines task was frequency based; therefore, it exposed phase lag more than the discrete task. The 2P sum-of-sines PIO ratings ranged from "a tendency of undesirable motions affecting task performance" to "sustained oscillations with possible divergence." However, none of the rate limits tested caused the aircraft to be uncontrollable.

Configuration 2DU CH ratings ranged from Level 1 to uncontrollable depending on task and rate limit. Handling qualities cliffs were discovered as pilots gave favorable comments during a good portion of a task and were then surprised as control rapidly degraded and the NT-33A automatic safety trip engaged. During one evaluation, the safety trip engaged at an elevator rate limit of 60 degrees per second during the discrete task. The same test condition was evaluated Level 1 during a different evaluation. With the standard NT-33A elevator rate limit, configuration 2DU was borderline Level 1. The discrete task exposed handling qualities deficiencies at higher elevator rate limit values than the sum-of-sines task. Only at an elevator rate limit of 20 degrees per second did the NT-33A safety trip engage for the sum-of-sines task compared to 60 degrees per second for the discrete task.

GROUND-BASED SIMULATION DATA

Methods and Conditions:

The test team flew 8.0 hours in LAMARS on 25 April 1997, to complete as many of the test points in Appendix A as possible. In general, the same procedures used when flying the NT-33A aircraft were used in LAMARS. One exception was that no safety pilot was required in LAMARS. Each pilot flew test conditions in the same order as in the NT-33A. The pilots, however, were not aware they were flying the test conditions in the same order, nor were they briefed on the results from flight test. Hence, the pilots were still "blind" to the test conditions being flown.

Results and Analyses:

Twenty-seven of the 36 test conditions flown on the NT-33A aircraft were flown by at least 2 pilots on LAMARS. Experiment number, aircraft configuration, task, rate limit, CH ratings, and PIO ratings are listed in Table 5. Table 5 (LAMARS pilot ratings) is structured in the same manner as Table 4 (NT-33A pilot ratings).

There were two issues concerning LAMARS that were not resolved:

1. Apparent stick force per g in LAMARS versus than the NT-33A aircraft, and

2. Tracking task commanded bank angle in the LAMARS versus the NT-33A aircraft.

The following results assume simulation on LAMARS was representative of the NT-33A. **Issues concerning the feel system and task on LAMARS should be examined to ensure they match what was flown on the NT-33A aircraft. (R)**[1]

Figures 5 and 6 show pilot ratings for both the discrete and sum-of-sines tasks from the LAMARS. The format of Figures 5 and 6 is identical to Figures 3 and 4 (NT-33A flight test results). The following overall trends and evaluations are broken down by aircraft configuration.

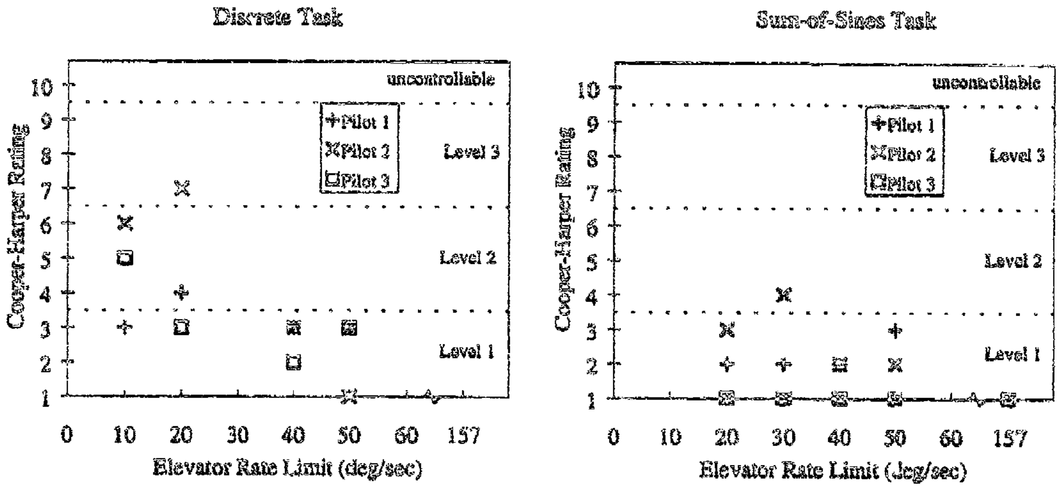
[1] The R within parentheses corresponds to the bolded recommendation in the Conclusions and Recommendations section of this report.

Table 5
PILOT RATINGS FOR LARGE AMPLITUDE MULTIMODE
AEROSPACE RESEARCH SIMULATOR PROGRAM (25 APRIL 1997)[1]

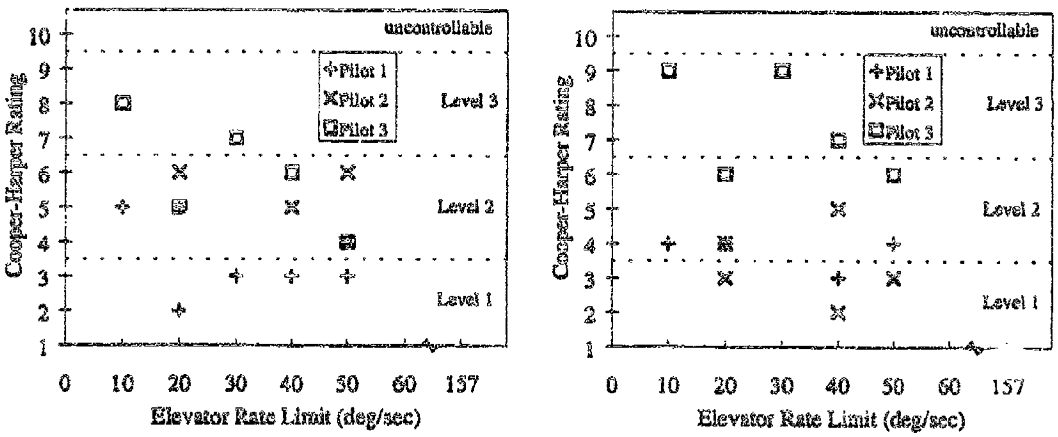
Exp	A/C	Task	RL	CHR	PIOR
40	2D	discrete	10	3 ‖ 6 ‖ 5	2 ‖ 4 ‖ 3
41	2D	discrete	20	4 ‖ 7 ‖ 3	2 ‖ 4 ‖ 2
42	2D	discrete	30	- ‖ - ‖ -	- ‖ - ‖ -
43	2D	discrete	40	3 ‖ 3/3 ‖ 2	2 ‖ 2/2 ‖ 1
44	2D	discrete	50	3 ‖ 1 ‖ 3	2 ‖ 1 ‖ 2
46	2D	discrete	157	- ‖ - ‖ -	- ‖ - ‖ -
47	2D	SOS	10	- ‖ - ‖ -	- ‖ - ‖ -
48	2D	SOS	20	2 ‖ 3 ‖ 1	2 ‖ 2 ‖ 1
49	2D	SOS	30	2 ‖ 4 ‖ 1	2 ‖ 2 ‖ 1
50	2D	SOS	40	2 ‖ 2 ‖ 1	2 ‖ 1 ‖ 1
51	2D	SOS	50	3 ‖ 2 ‖ 1	2 ‖ 1 ‖ 1
53	2D	SOS	157	- ‖ - ‖ 1	- ‖ - ‖ 1
54	2P	discrete	10	5 ‖ - ‖ 8	3 ‖ - ‖ 4
55	2P	discrete	20	2 ‖ 5/6 ‖ 5	2 ‖ 3/4 ‖ 2
56	2P	discrete	30	3 ‖ - ‖ 7	2 ‖ - ‖ 4
57	2P	discrete	40	3 ‖ 5 ‖ 6	2 ‖ 4 ‖ 4
58	2P	discrete	50	3 ‖ 4/6 ‖ 4	2 ‖ 3/4 ‖ 2
60	2P	discrete	157	- ‖ - ‖ -	- ‖ - ‖ -
61	2P	SOS	10	4 ‖ - ‖ 9	2 ‖ - ‖ 5
62	2P	SOS	20	4 ‖ 3/4 ‖ 6	2 ‖ 2/2 ‖ 4
63	2P	SOS	30	- ‖ - ‖ 9	- ‖ - ‖ 4
64	2P	SOS	40	3 ‖ 2/5 ‖ 7	2 ‖ 1/3 ‖ 4
65	2P	SOS	50	4 ‖ 3 ‖ 6	2 ‖ 1 ‖ 4
67	2P	SOS	157	- ‖ - ‖ -	- ‖ - ‖ -
69	2DU	discrete	20	4/10 ‖ 10 ‖ 5/8	2/5 ‖ 5 ‖ 3/3
70	2DU	discrete	30	10 ‖ - ‖ 6	5 ‖ - ‖ 3
71	2DU	discrete	40	3 ‖ 2/5 ‖ 3	2 ‖ 1/4 ‖ 2
72	2DU	discrete	50	2 ‖ 3 ‖ 4	2 ‖ 2 ‖ 2
73	2DU	discrete	60	- ‖ 5 ‖ 5	- ‖ 3 ‖ 3
74	2DU	discrete	157	- ‖ - ‖ 6	- ‖ - ‖ 2
76	2DU	SOS	20	3 ‖ 4 ‖ 8	2 ‖ 2 ‖ 4
77	2DU	SOS	30	- ‖ 2 ‖ 3	- ‖ 1 ‖ 2
78	2DU	SOS	40	3 ‖ 5 ‖ 1	2 ‖ 3 ‖ 1
79	2DU	SOS	50	3 ‖ 2 ‖ 2	2 ‖ 1 ‖ 2
80	2DU	SOS	60	- ‖ 5 ‖ 2	- ‖ 3 ‖ 1
81	2DU	SOS	157	- ‖ - ‖ -	- ‖ - ‖ -

Notes:
1. Exp - Calspan designated experiment numbers which appear on all HUD video tapes
2. RL - elevator rate limit in degrees per second
3. PIOR - pilot-induced oscillation rating
4. A/C - aircraft configuration
5. SOS - sum-of-sines
6. CHR - Cooper-Harper rating
7. "–" - pilot did not fly the test condition

[1] Multiple ratings by same pilot separated by "/". Order of pilot ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.



a. Aircraft Configuration 2D



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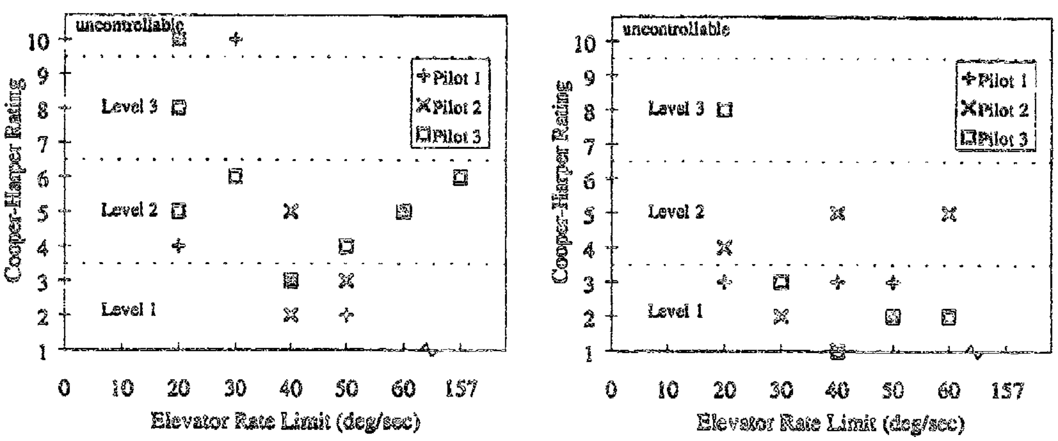
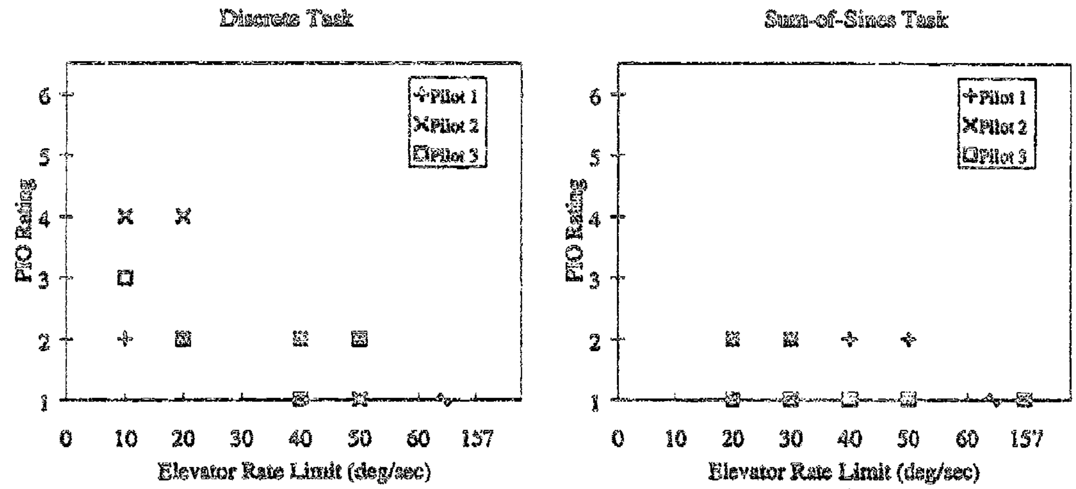
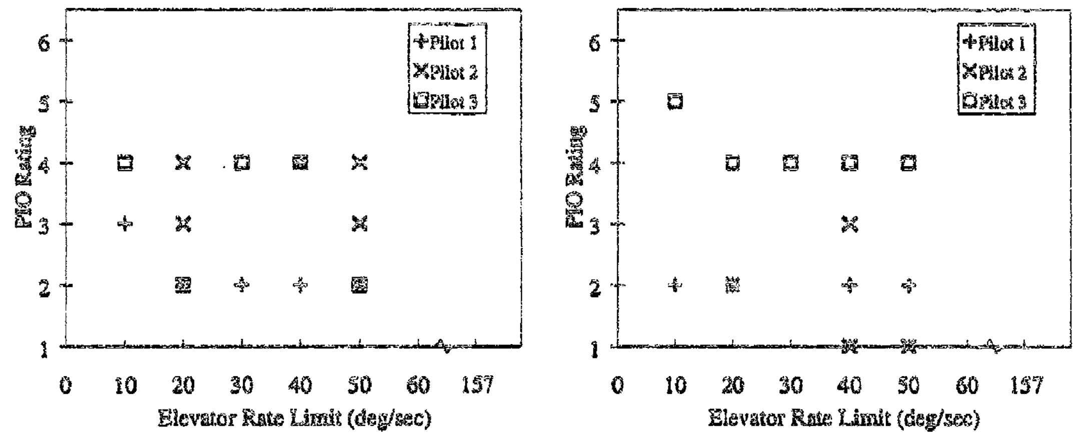


c. Aircraft Configuration 2DU

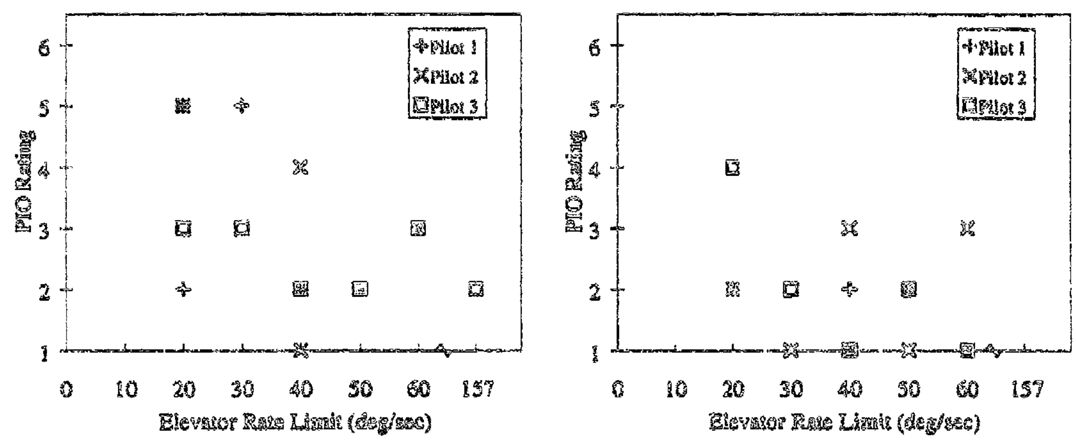
Figure 5 Cooper-Harper Ratings for Large Amplitude Multimode Research Simulator Program (25 April 1997)



a. Aircraft Configuration 2D



b. Aircraft Configuration 2P



c. Aircraft Configuration 2DU

Figure 6 Pilot-Induced Oscillation Ratings for Large Amplitude Multimode Research Simulator Program (25 April 1997)

Overall, configuration 2D was Level 1 in LAMARS with no PIO tendency for elevator rate limits of 40 degrees per second and above. The PIOs were seen for elevator rate limits of 20 degrees per second and below. Ratings for the discrete task were worse than those for the sum-of-sines task.

Configuration 2P was Level 2. Task did not appear to affect pilot ratings.

Configuration 2DU had an apparent handling qualities cliff between elevator rate limits of 30 and 40 degrees per second. Ratings were highly scattered. Ratings for the discrete task were worse than those for the sum-of-sines task.

COMPARISON OF LAMARS TO NT-33A FLIGHT TEST RESULTS

Figures 7 and 8 show pilot ratings from LAMARS and the NT-33A aircraft. Overall, configurations 2D and 2P had good correlation between in-flight and ground-based simulation. Ratings seen in flight were generally seen in LAMARS. Configuration 2DU had poor correlation between in-flight and ground-based simulation. The CH ratings differed by as much as 6, and PIO ratings differed by as much as 3.

Pilots gave the following general differences between LAMARS and the NT-33A aircraft. These comments were for all configurations; however, they were most prevalent for configuration 2DU. The differences were as follows:

1. It was much easier to track and obtain desired performance in LAMARS.

2. It was easier to discern differences between test conditions in the NT-33A aircraft.

3. The LAMARS pitch stick forces appeared to be heavier than the NT-33A aircraft for moderate to high-g loadings. Uncontrollable test conditions seen in-flight occurred under high-g aggressive pulls. A heavy stick tended to absorb pilot aggressiveness.

4. The LAMARS stick grip was an F-15-type; bigger and more difficult to grasp. In the first 54 evaluations, the stick grip was slightly loose giving the impression of free play.

5. Since the variable stability system limits that tripped off the NT-33A aircraft were not modeled in LAMARS, the pilot felt he could fly bad configurations longer.

6. Steady-state pitch response was difficult to evaluate in LAMARS due to lack of sustained g feedback.

7. Lower pilot gains in LAMARS were attributed to lack of total environmental feedback cues (g, visual, engine noise, etc.) that were present in-flight.

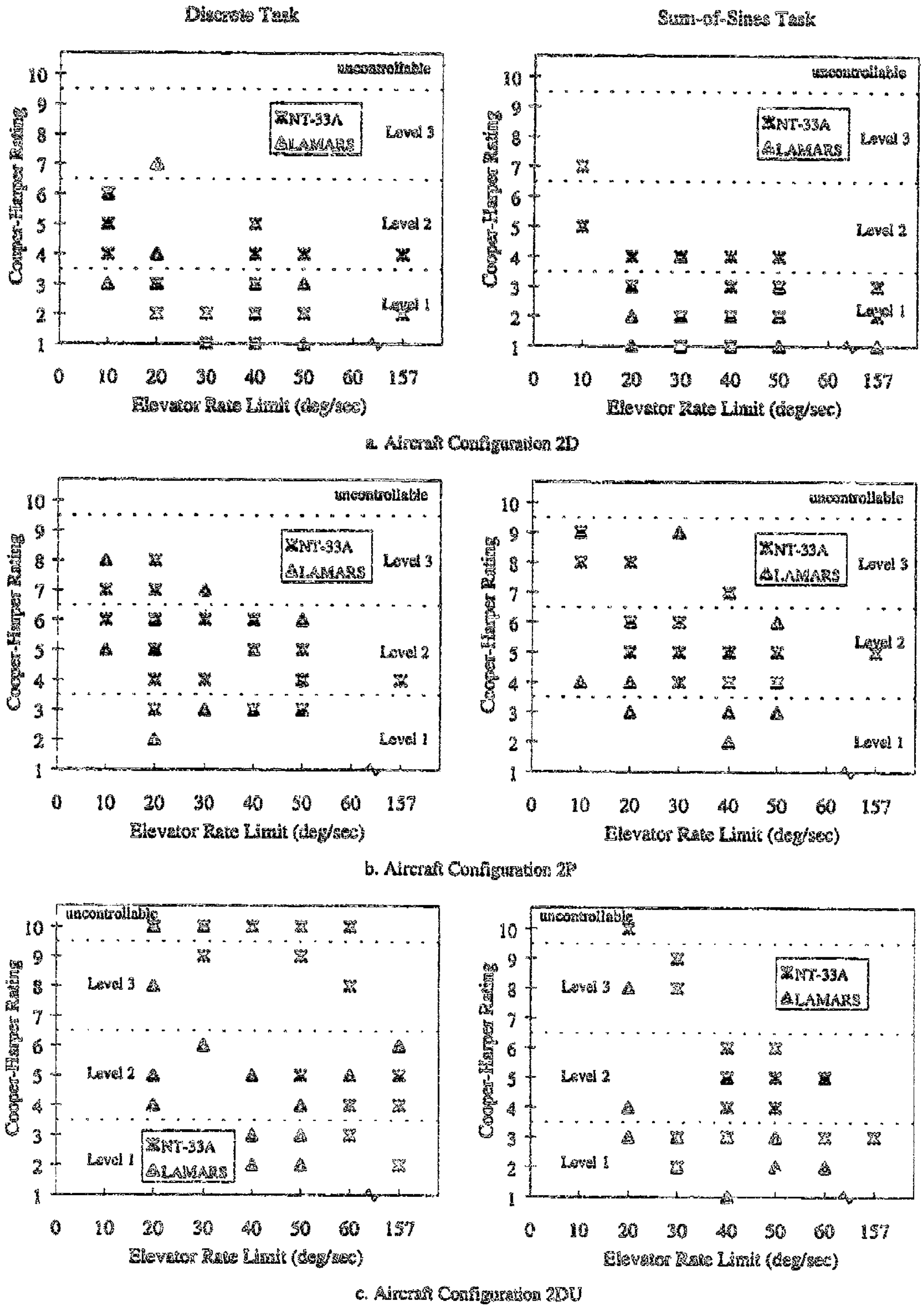
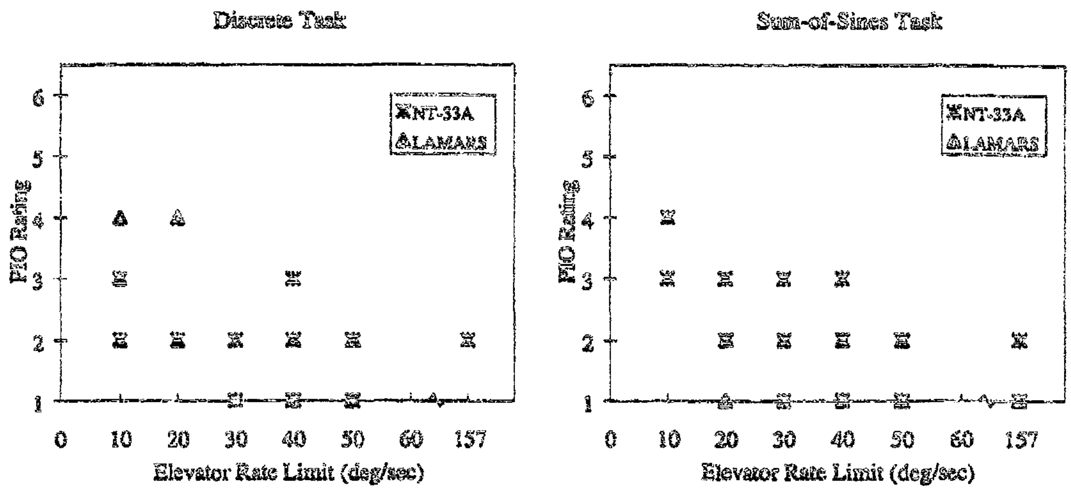
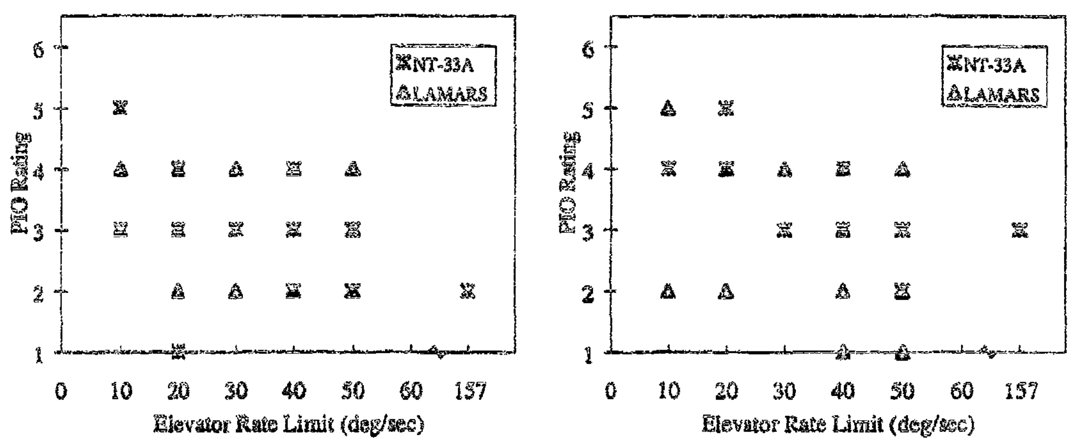


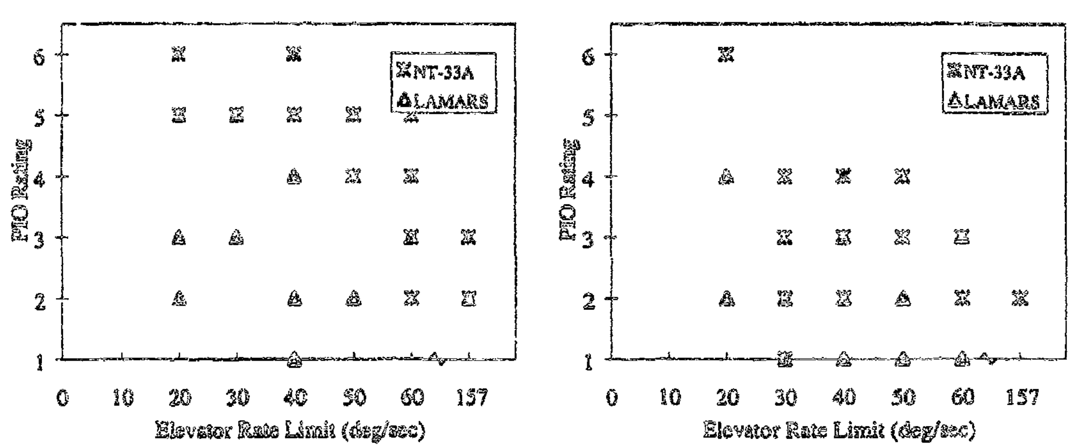
Figure 7 Comparison of Cooper-Harper Ratings Between Flight and Simulation



a. Aircraft Configuration 2D



b. Aircraft Configuration 2P



c. Aircraft Configuration 2DU

Figure 8 Comparison of Pilot-Induced Oscillation Ratings Between Flight and Simulation

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CONCLUSIONS AND RECOMMENDATIONS

All test objectives were met. Three aircraft configurations were verified and flown on the NT-33A in-flight simulator aircraft and the ground-based Large Amplitude Multimode Aerospace Research Simulator (LAMARS) using two head-up display tracking tasks and seven elevator rate limits. In total, 36 test conditions were flown by at least 2 pilots in the NT-33A aircraft, while 27 test conditions were flown by at least 2 pilots in LAMARS. A database of pilot comments and ratings, as well as time histories, was generated for both in-flight and ground-based simulation.

As predicted, configuration 2D did not exhibit PIO tendency in flight until an elevator rate of 10 degrees per second was used. Pilots commented that configuration 2D felt "springy" at elevator rate limits of 50 degrees per second and above. Consequently, lower values (30 to 40 degrees per second) tended to "smooth" the aircraft response resulting in better ratings. As predicted, configuration 2P was Level 2 in flight with no rate limiting and degraded with rate limiting. Also as predicted, configuration 2DU was borderline Level 1 in flight with no rate limiting and became strongly divergent when rate limiting was reached.

As of the publishing of this report two issues remained outstanding regarding differences between LAMARS and the NT-33A test setups.

> ***Issues concerning the feel system and task on LAMARS should be examined to ensure they match what was flown on the NT-33A aircraft. (Page 9)***

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APPENDIX A

TEST ITEM DESCRIPTION

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TEST ITEM DESCRIPTION

GENERAL

The item under test was defined as three different aircraft models, a range of rate limits, and two different tasks. Each test condition evaluated consisted of a particular aircraft model, task, and rate limit. Figure A1 graphically depicts the definition of each test condition.

An example of an individual test condition would be "2D, 20 degrees per second, sum-of-sines." This defines the aircraft longitudinal dynamics, the rate limit, and the tracking task to be evaluated by the pilot for a particular test condition. This test condition was then evaluated by one or more pilots with the data in Appendix D collected. For the NT-33A in-flight simulator testing, a complete list of the test conditions evaluated is provided in Appendix C.

The rest of the test item description provides a more detailed description of:

1. The three aircraft models,

2. Rate limits,

3. The two tracking tasks, and

4. The test assets.

AIRCRAFT MODELS

The aircraft model was divided into separate longitudinal and lateral-directional control models. The longitudinal control model for each of the three configurations is described below. The lateral-directional control model was identical for each of the three configurations, 2D, 2P, and 2DU and is described after the three different longitudinal models are presented.

Longitudinal Control Model:

General structure of the three longitudinal control models is shown in Figure A2.

The differences in aircraft longitudinal models were in the simulated airframe plus filters and the feedback. The following subsections describe each of the blocks in Figure A2.

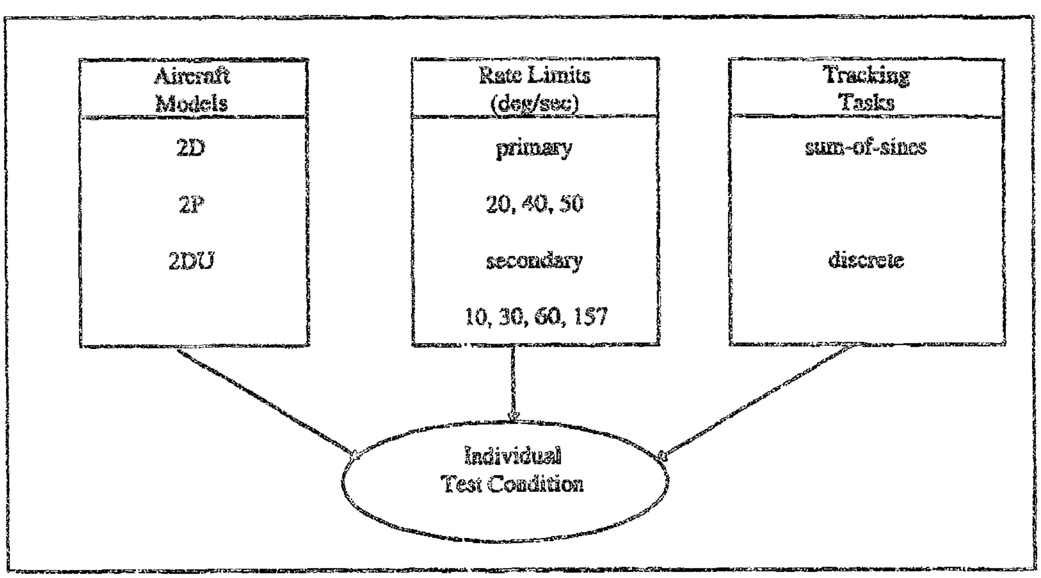

Figure A1 Definition of Individual Test Conditions

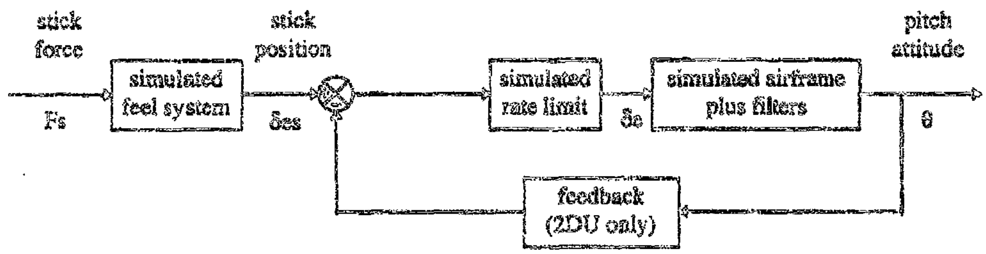

Figure A2 Block Diagram of Longitudinal System

Simulated Feel System:

For each of the three configurations, 2D, 2P, and 2DU, the simulated feel system was identical. The longitudinal simulated feel system dynamics had a damping ratio of 0.65 and a natural frequency of 23 radians per second. Spring gradient was 25 pounds/g from 1.0 to 1.8 g and 7 pounds/g above 1.8 g. The elevator gearing (control sensitivity) was nonlinear as shown in Figure A3.

The lateral simulated feel system dynamics were designed for good control harmony with a damping ratio of 0.6 and a natural frequency of 22 radians per second. Spring gradient was 6.5 pounds/inch. All evaluations were flown feet on the floor (i.e., no rudder inputs).

Airframe Plus Filters:

The short-period approximations for θ/δ_e are listed in Table A1. Configuration 2D was the baseline ···e. Its dynamics were based on a configuration evaluated in the Neal-Smith experiment (Reference 7) where it was a good (flying qualities Level 1) airplane. Configuration 2P was developed for this program by multiplying 2D by a first-order lag of 4/(s+4). Configuration 2DU was designed for this program as well; it was intended to be similar to 2D when augmentation was active (as listed in Table A1). Without augmentation, such as when the rate limit was reached, 2DU had a divergent short-period mode with a time to double of approximately 3.5 seconds.

In the Neal-Smith experiment (Reference 7), force command sensing was used. That is, aircraft commands were based on pilot-applied forces and the cockpit stick's feel system was in parallel. For this experiment it was decided that position sensing would be used. This is more consistent with the majority of current operational aircraft.

Lateral-Directional System:

A set of lateral-directional characteristics, presented in Table A2, was selected for all three aircraft models. Primarily, they were chosen to be good enough as to not detract from the longitudinal rate limit evaluation.

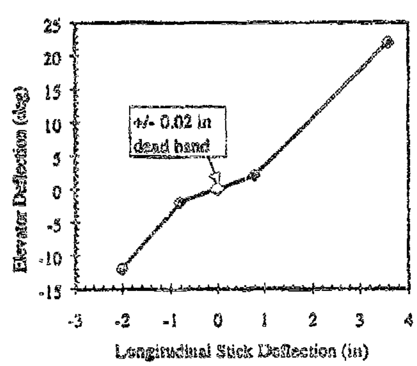

Figure A3 Nonlinear Stick Command Gradient

Table A1
AIRFRAME PLUS FILTERS

Configuration	$\theta/\delta_e(s)$
2D	$\dfrac{7(s+1.20)e^{-0.040s}}{s[s^2+2(0.74)(4.86)s+4.86^2]}$
2P	$\dfrac{28(s+1.20)e^{-0.040s}}{s(s+4)[s^2+2(0.74)(4.86)s+4.86^2]}$
2DU	$\dfrac{7(s+1.20)e^{-0.040s}}{s[s^2+2(0.64)(5.17)s+5.17^2]}$

Table A2
LATERAL-DIRECTIONAL SYSTEM

$\omega_d \cong 2.9$ rad/sec
$\zeta_d \cong 0.73$
$\lvert\phi/\beta\rvert \cong 0.5$
$\tau_r \cong 0.17$ sec

Notes: 1. ω_d - dutch roll frequency
2. ζ_d - dutch roll damping ratio
3. ϕ/β - phi to beta ratio
4. τ_r - roll mode time constant

RATE LIMITS

The elevator rate limits were initially determined using the ground-based simulation on the USAF Test Pilot School (TPS) simulator. The range of rate limits were then verified initially in check-out flights by Calspan and again on the initial flight test at Edwards AFB. A full description of the procedures used to determine the range of rate limits is provided in the main portion of the report in the Test Procedures and Results section.

HUD TRACKING TASKS

Two head-up display (HUD) tracking tasks were utilized to evaluate the handling qualities of the different aircraft longitudinal dynamics with different rate limits. For each of the two tasks the pilot was directed to keep the "target" in the desired/adequate tracking reticle. The same HUD tasks and displays were utilized in the NT-33A in-flight simulator and the ground-based Large Amplitude Multimode Aerospace Research Simulator (LAMARS). This section describes the shape of both the target and the tracking reticle that appeared on the HUD for each of the two tasks.

HUD Display Symbology/Criteria:

During each test point the pilot was directed to keep the target within the desired criteria whenever possible. Cooper-Harper (CH) and PIO ratings were based on the pilot's evaluation of when he was able to attain desired and/or adequate performance. A complete description of desired and adequate performance is provided in Appendix D. The shape of the target and the shape of the desired and adequate criteria are provided in Figure A4. It should

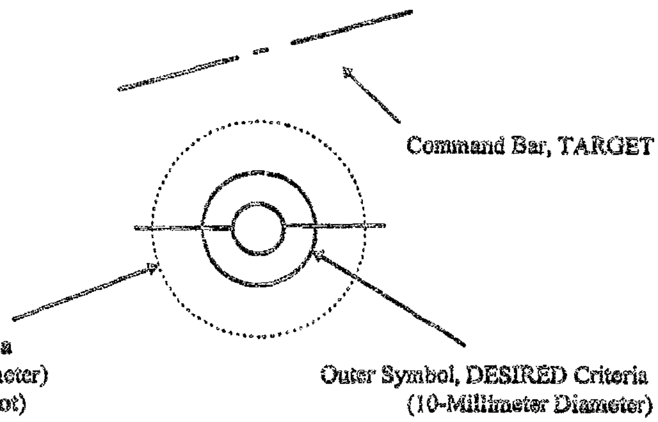

Figure A4 HUD Tracking Task Symbology

be noted that the pilot had to estimate the size of the adequate criteria due to limitations in the ability to reprogram the HUD display.

HUD Tracking Task 1, Discrete Task:

The first HUD tracking task was an "off-the-shelf" task used by Calspan. The task had been previously used in the Navy TPS curriculum for a handling qualities demonstration of a variable stability aircraft. The task directed the target through discrete steps and ramps synchronized in pitch and roll. The nodes for both pitch and roll commands of the target are listed in Table A3. Figure A5 shows these commands plotted versus time.

The command bar on the HUD was then driven in pitch by Equation 1. Pitch error was limited to ±3 degrees. This limit prevented the command bar from flying outside the HUD field of view.

$$\text{pitch error} = 0.86\,(\text{pitch}_{cmd} - \theta_{NT\text{-}33A} + \theta_{bias}) \quad (1)$$

where:

pitch_{cmd} = pitch command in Figure A5 (deg)

$$\theta_{NT\text{-}33A} = \frac{\text{NT-33A pitch angle}}{\cos(\text{NT-33A bank angle})} \quad (\text{deg})$$

θ_{bias} = trim NT-33A pitch angle (deg)

The command bar on the HUD was driven in roll by Equation 2. Roll error was limited to ±70 degrees.

$$\text{roll error} = 0.88\,(\phi_{NT\text{-}33A} - \text{roll}_{cmd} + \phi_{bias}) \quad (2)$$

where:

$\phi_{NT\text{-}33A}$ = NT-33A roll angle (deg)

roll_{cmd} = roll command in Figure A5 (deg)

ϕ_{bias} = trim NT-33A roll angle (deg)

HUD Tracking Task 2, Sum-of-Sines:

The sum-of-sines task was developed by Hoh Aeronautics, Inc., using Equation 3. This task has been used in several fixed- and moving-base simulations. Pilot-vehicle dynamic information can be extracted from the data generated by this task.

Table A4 lists values for the parameters in Equation 3. The sum-of-sines task was a pitch-only task and is shown in Figure A6. A 5-second ramp-in was used where the signal went from zero to full scale. A 1.25-second ramp-out where the signal went from full scale to zero was used at time equals

Table A3
DISCRETE NODES

Time (sec)	Pitch Command (deg)	Roll Command (deg)	Time (sec)	Pitch Command (deg)	Roll Command (deg)
0.00	0.00	0.00	75.00	-2.00	-70.00
0.10	2.00	0.60	75.10	0.00	-70.00
5.00	2.00	30.00	77.50	0.00	-70.00
5.50	3.00	30.60	80.00	0.00	30.00
10.00	3.00	60.00	80.10	0.00	30.00
10.10	2.00	30.00	82.50	0.00	30.00
12.50	2.00	30.00	85.00	0.00	30.00
15.00	0.33	30.00	87.50	0.00	0.00
17.50	-1.33	-45.00	90.00	0.00	0.00
20.00	-3.00	-30.00	90.10	0.00	30.00
22.50	2.00	-15.00	92.50	0.00	30.00
25.00	2.00	0.00	92.60	0.00	0.00
25.10	2.00	15.00	95.00	0.00	0.00
27.50	2.00	30.00	95.10	-1.00	0.00
30.00	0.00	45.00	97.50	-1.00	0.00
35.00	-3.00	45.00	97.60	-1.00	-70.00
35.10	-2.00	43.50	100.00	-1.00	-70.00
37.50	-2.00	7.50	102.50	-1.67	-70.00
37.60	-1.00	6.00	107.50	-3.00	-23.30
40.00	-1.00	-30.00	110.00	-3.00	0.00
42.50	-1.00	-30.00	112.50	-3.00	0.00
42.60	3.00	-30.00	112.60	-1.00	60.00
45.00	3.00	-30.00	115.00	-1.00	60.00
45.10	3.00	0.00	115.10	3.00	60.00
52.50	3.00	70.00	117.50	3.00	60.00
55.00	3.00	70.00	117.60	3.00	-30.00
60.00	1.50	70.00	120.00	3.00	-30.00
65.00	0.00	-23.30	120.10	2.00	-30.00
67.50	0.00	-70.00	122.50	2.00	-30.00
70.00	0.00	-70.00	126.60	1.00	-15.00
70.10	0.00	-70.00	127.50	1.00	-15.00
72.50	0.00	-70.00	127.60	0.00	0.00
72.60	-2.00	-70.00	140.00	0.00	0.00

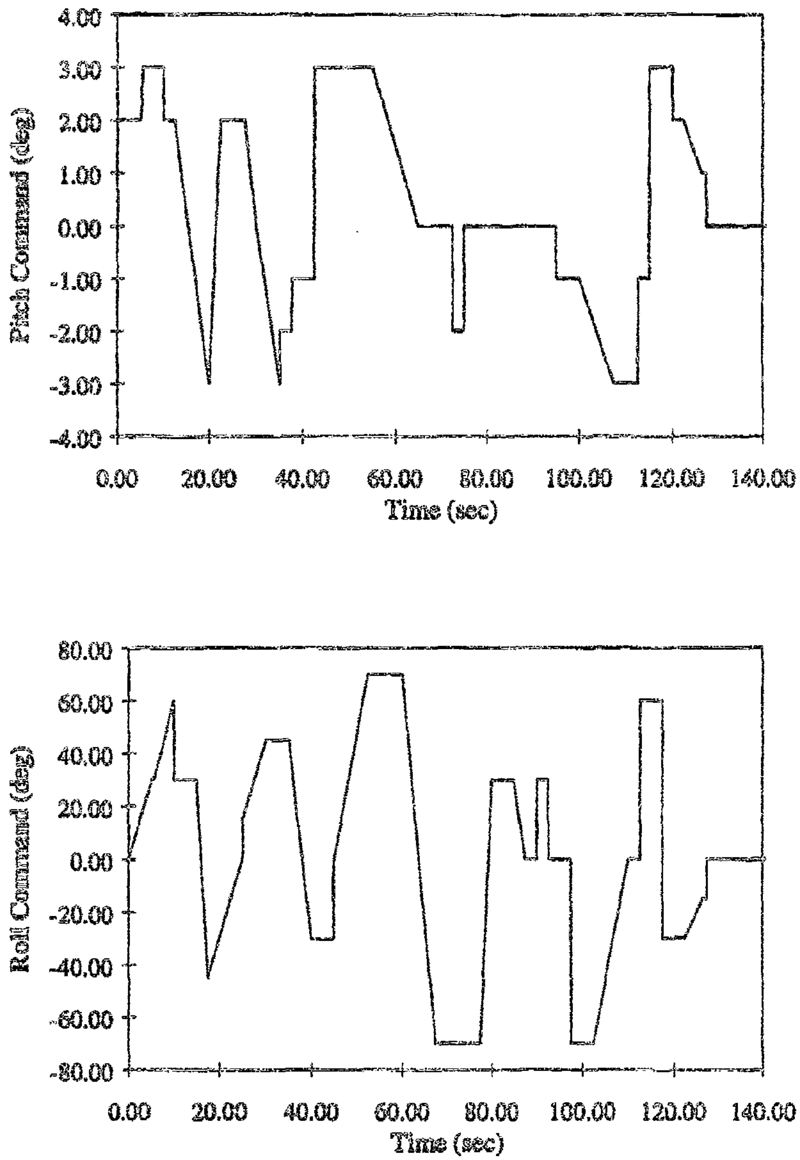

Figure A5 Synchronized Pitch and Roll Discrete Tracking Task

73 seconds. The task was designed to provide continuous commands, but limitations of the NT-33A computer required that the command signal to the HUD be updated only four times every second. Linear interpolation between command points was used to smooth the signal.

$$\{\sum_{i=1}^{7} A_i \sin(\omega_i t)\}$$

where:

$$\omega_i = 2\pi \frac{N_i}{63} \quad \text{(rad/sec)} \qquad (3)$$

Table A4
SUM-OF-SINES PARAMETERS

i	A_i	N_i	ω_i
1	-1.00	2	0.19947
2	1.00	5	0.49867
3	1.00	9	0.89760
4	0.50	14	1.39626
5	-0.20	24	2.39359
6	0.20	42	4.18879
7	-0.08	90	8.97598

Notes: 1. A_i - Amplitude
2. N_i - Natural Frequency Gain
3. ω_i - Natural Frequency

TEST ASSETS

USAF TPS Simulator:

The USAF TPS simulator was a PC-based simulator, manufactured by High Plains Engineering, Mojave, California. It was fixed-base and portable; designed for use in the classroom. This simulator was unique in that it was designed specifically for high-fidelity, handling quality simulations, which demand minimum added time delay. The total time delay was the sum of computational delay and video system delay. For PIO simulations, the computational rate was 200 Hz, with video refresh at 72 Hz, for a worst-case time delay of 18.9 milliseconds.

The cockpit ergonomics were representative of a modern fighter. A mechanical control stick was used which approximated the pitch axis feel system dynamics of the Neal-Smith flight tests (Reference 7). Simulations were done using stick deflection to drive the aerodynamic models.

The actuator dynamics and rate limiting were selectable from the graphical user interface. The actuator model used had first order dynamics with servo-valve rate limiting. This resulted in increased phase lag of the actuator when rate limiting was encountered.

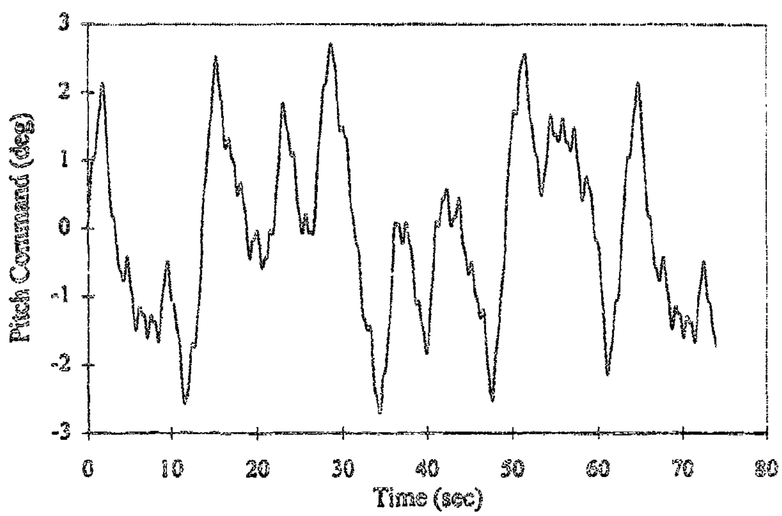

Figure A6 Sum-of-Sines Task

The NT-33A Aircraft:

The in-flight test platform was the USAF Flight Dynamics Laboratory NT-33A aircraft, S/N 51-4120. The NT-33A aircraft, modified and operated by Calspan under USAF contract as an in-flight simulator, was an extensively modified Lockheed T-33 jet trainer (Reference 8). The original T-33 nose section was replaced by an F-94 nose, providing space for the recording equipment and the electronic components of the variable stability flight control system. The front seat controls were replaced by a full-authority, fly-by-wire flight control system and a variable response artificial feel system. The evaluation was conducted from the front cockpit through a center stick and rudder pedal arrangement. The rear cockpit contained the original mechanical flight control system of the T-33 jet trainer. The rear cockpit safety pilot served as the system operator by setting up the research experiments, aircraft configurations, and HUD formats. The NT-33A programmable analog and digital flight control system allowed the airplane to assume any of the pitch flight control configurations (Figures A7 through A10). A fully programmable HUD complemented the variable stability features of the NT-33A for cockpit display, research and evaluation, and allowed the HUD tracking tasks to be displayed.

The NT-33A had a variable stability system (VSS) disengagement mechanism which allowed the pilot to manually disengage the VSS by hands-on throttle and stick, as required for test or safety. The VSS automatically disengaged when the parameters exceeded the criteria listed in Table A5. When disengaged, the NT-33A aircraft reverted to normal T-33 flight dynamics and the safety pilot took control of the aircraft. All time-history data were recorded using the onboard Ampex AR700 flight data recorder. In-flight data parameters, collection rate, and valid ranges are defined in Appendix D. The HUD video/audio recorder system and a separate audio recording system were used to record pilot comments.

Sorties 8 and 9 were flown with an aerial refueling probe installed which was assumed to not affect the flight characteristics of the test conditions.

Large Amplitude Motion Analysis Research Simulator:

The LAMARS was a motion-based, 20-foot dome with two side projectors, each with a 40.5- by 30-degree field of view (FOV), and a center projector with a 45- by 30-degree FOV. The total FOV was 135 degrees without gaps.

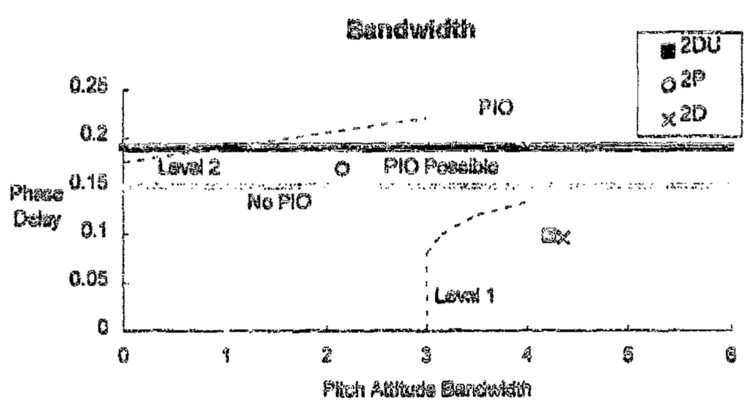

Figure A7 Predicted Handling Qualities and Pilot-Induced Oscillation Susceptibility Using Bandwidth Criterion

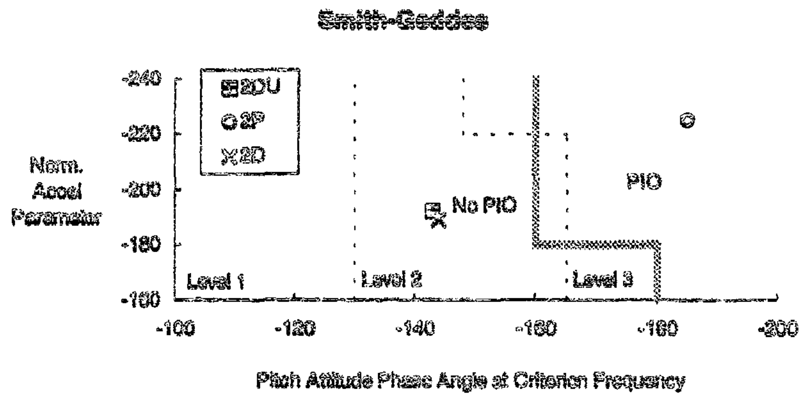

Figure A8 Predicted Handling Qualities and Pilot-Induced Oscillation Susceptibility Using Smith-Geddes Criterion

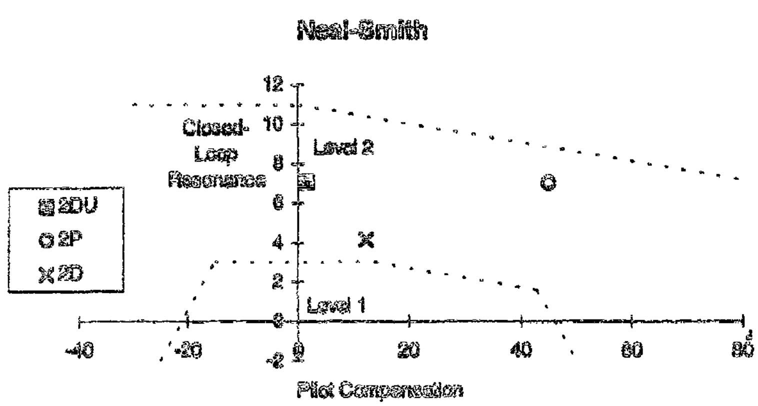

Figure A9 Predicted Handling Qualities Using Neal-Smith Criterion

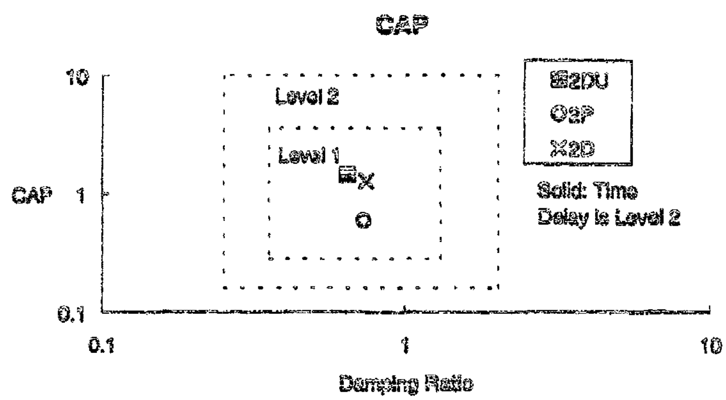

Figure A10 Predicted Handling Qualities Using Control Augmentation Parameter Criterion

Table A5
NT-33A VARIABLE STABILITY SYSTEM SAFETY TRIP CRITERIA

Safety Trip Parameters	Criteria
N_z	+4.8 g/-0.3 g
N_y	±0.25 g
Digital System	computer stops outputting square wave (computer alive signal, transitions at end of each frame)
δ_e servo (elevator)	±6-deg error between actual and command at servo amplifier
δ_r servo (rudder)	±18-deg error between actual and command at servo amplifier
δ_a servo (aileron)	±24-deg error between actual and command at servo amplifier

Notes:
1. N_z - longitudinal acceleration
2. N_y - lateral acceleration
3. δ_e - elevator deflection
4. δ_a - aileron deflection
5. δ_r - rudder deflection

APPENDIX B

AIRCRAFT MODEL VALIDATION

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AIRCRAFT MODEL VALIDATION

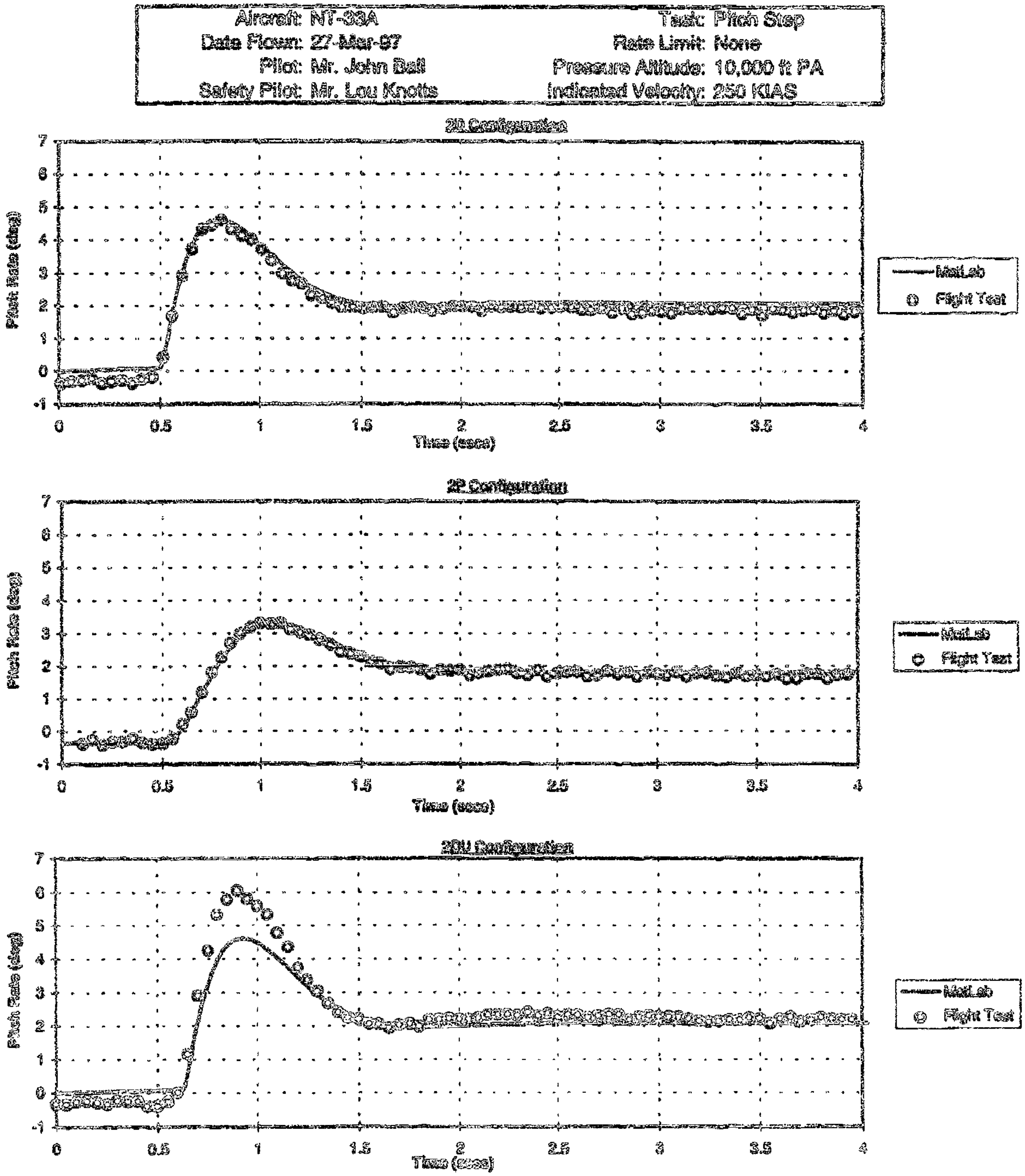
GENERAL

The following model validation results are provided in this appendix.

1. Comparison of time-domain pitch response from the NT-33A flight test and MATLAB® 4.2c predictions. Comparisons are provided for the 2D, 2P, and the 2DU aircraft models (See Table A1).

2. Flight test frequency response, phase and magnitude, for the aircraft models, 2D, 2P, and 2DU.

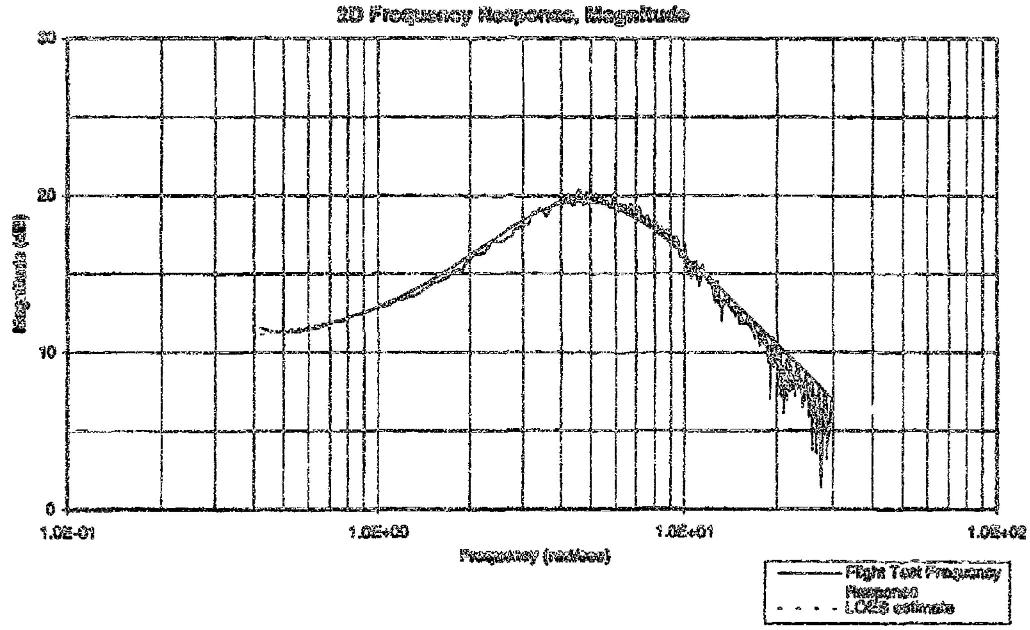
The frequency response was generated with data from 40-second manual longitudinal stick sweeps. The flight test frequency response is compared to a Lower Order Equivalent System (LOES) estimation for 2nd order response (Figures B1 through B4). The LOES estimation was generated with a modified MIL-STD-1797A (Reference 6) weighting function. The LOES 2nd order parameters (ζ_{sp}, $\omega_{n\ sp}$, $T_{\theta 2}$) are summarized in the Test and Evaluation section of this report (Table 2).

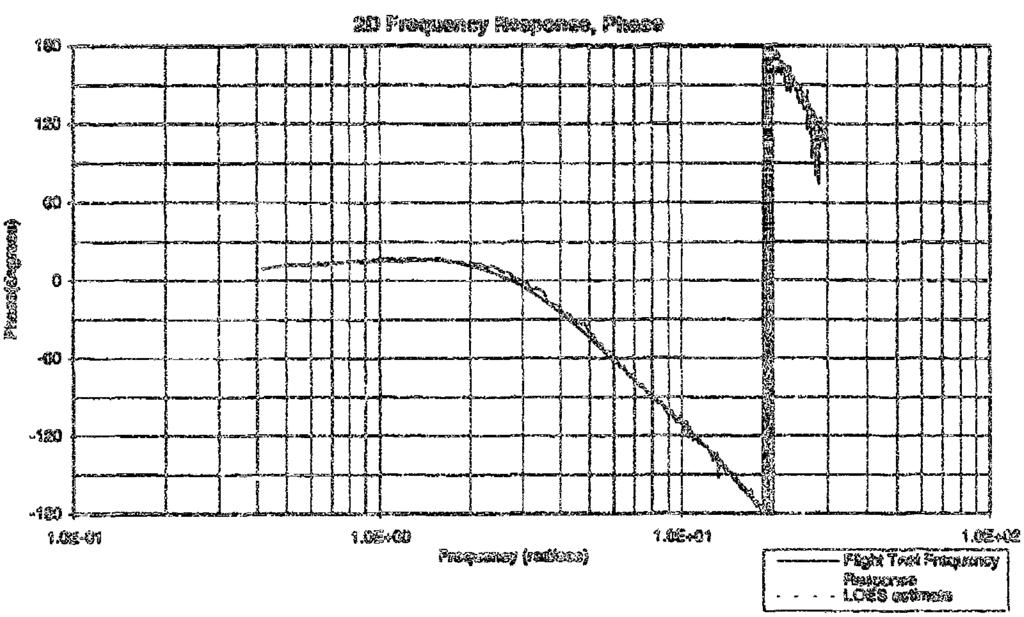


Notes: 1. Aircraft longitudinal dynamics for 2D, 2P, and 2DU are defined in Appendix A.
2. Preflight predictions were generated with MATLAB® 4.2c.

Figure B1 Comparison of NT-33A Flight Test Aircraft Model Pitch-Step Response to Preflight Predictions for 2D, 2P, 2DU (No Rate Limiting)

Aircraft: NT-33A	Task: Freq. Response
Date Flown: 27-Mar-97	Rate Limit: None
Pilot: Mr. John Ball	Pressure Altitude: 10,000 ft PA
Safety Pilot: Mr. Lou Knotts	Indicated Velocity: 250 KIAS

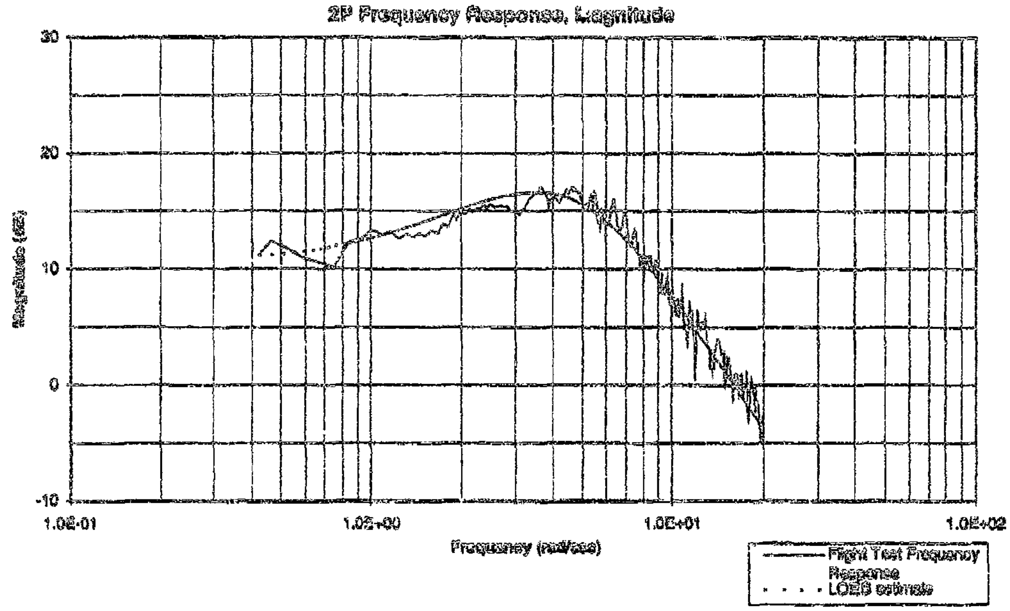


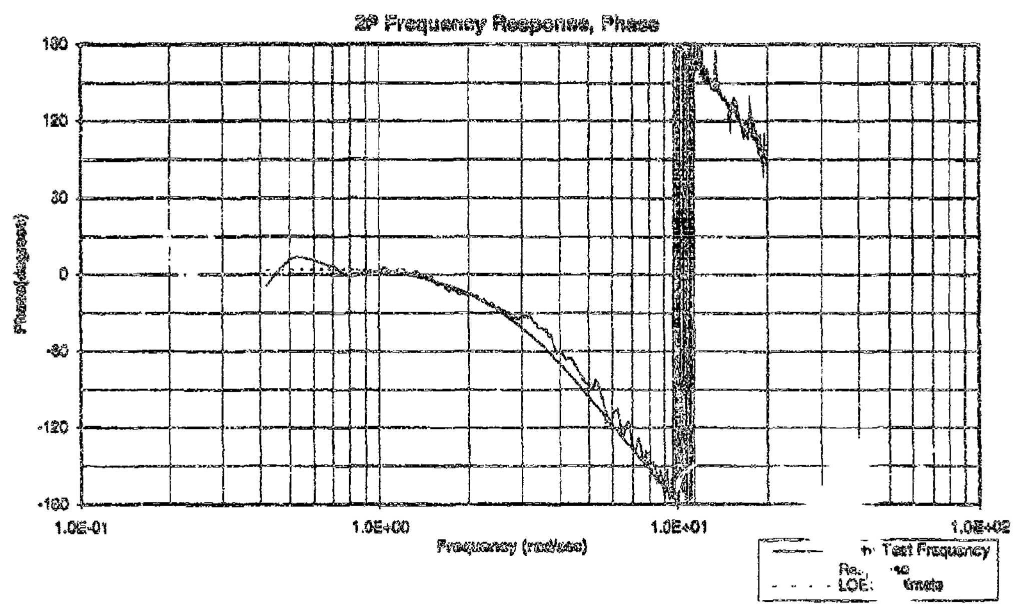


Notes: 1. Aircraft longitudinal dynamics for the 2D configuration are defined in Appendix A.
2. Flight test frequency response was generated from a 40-second manual frequency sweep.
3. The LOES estimation was generated with a modified MIL-STD-1797A (Reference 6) weighting function.

Figure B2 Comparison of NT-33A Flight Test Pitch Frequency Response to Lower Order Equivalent Systems (LOES) Estimation for the 2D Aircraft Model

Aircraft: NT-33A	Task: Freq. Response
Date Flown: 27-Mar-97	Rate Limit: None
Pilot: Mr. John Ball	Pressure Altitude: 10,000 ft PA
Safety Pilot: Mr. Lou Knotts	Indicated Velocity: 250 KIAS

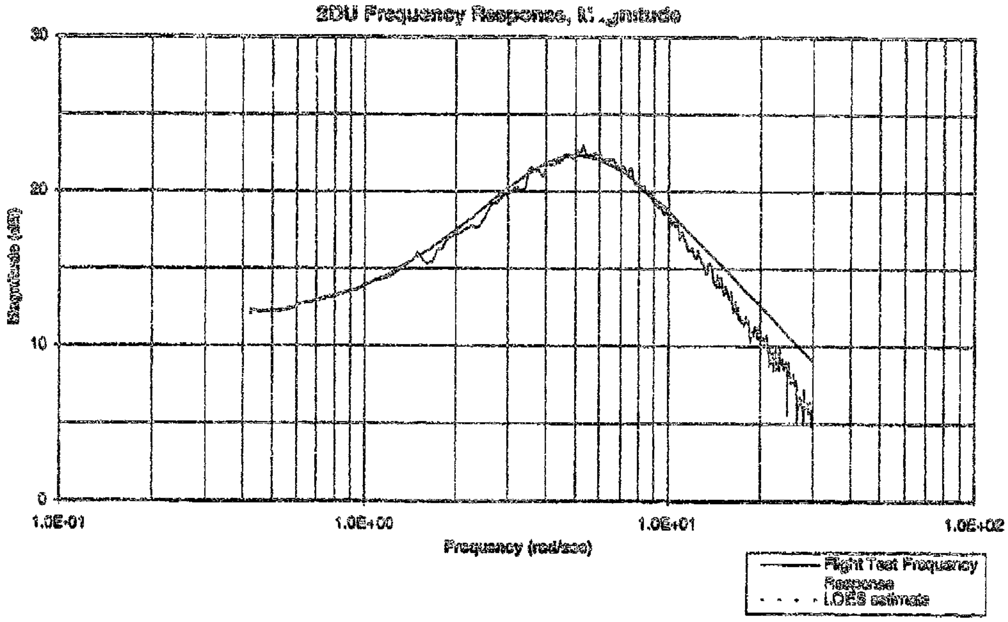


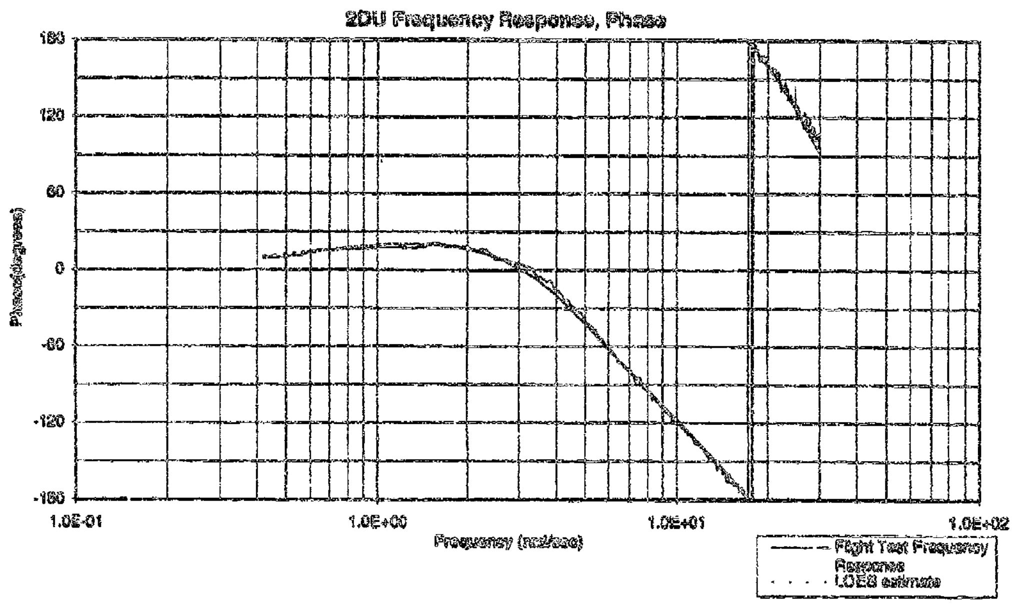


Notes:
1. Aircraft longitudinal dynamics for the 2P configuration are defined in Appendix A.
2. Light test frequency response was generated from a 40-second manual frequency sweep.
3. The LOES estimation was generated with a modified MIL-STD-1797A (Reference 6) weighting function.

Figure B3 Comparison of NT-33A Flight Test Pitch Frequency Response to Lower Order Equivalent Systems (LOES) Estimation for the 2P Aircraft Model

Aircraft: NT-33A	Task: Freq. Response
Date Flown: 27-Mar-97	Rate Limit: None
Pilot: Mr. John Ball	Pressure Altitude: 10,000 ft PA
Safety Pilot: Mr. Lou Knotts	Indicated Velocity: 250 KIAS





Notes: 1. Aircraft longitudinal dynamics for the 2DU configuration are defined in Appendix A.
2. Flight test frequency response was generated from a 40-second manual frequency sweep.
3. The LOES estimation was generated with a modified MIL-STD-1797A (Reference 6) weighting function.

Figure B4 Comparison of NT-33A Flight-Test Pitch Frequency Response to Lower Order Equivalent Systems (LOES) Estimation for the 2DU Aircraft Model

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APPENDIX C

NT-33A FLIGHT TEST RESULTS

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NT-33A FLIGHT TEST RESULTS

GENERAL

This appendix contains the NT-33A flight test results including individual Cooper-Harper (CH) and PIO ratings, and pilot comments. The results of each test condition flown are displayed on two pages. The data are presented in the order defined in Table C1.

The following information is displayed for each test condition (Tables C2 through C73 and Figures C1 through C36):

1. A summary of the overall evaluation of the configuration. This summary comes from postprocess accumulation of pilot comments and ratings. The Cooper-Harper ratings (CHRs) are separated by a "‖" when the evaluation pilot has changed and by a "/" when additional ratings are made by the same pilot. For example, 4‖5/4‖6* means that pilot 1 gave it a CHR of 4, while pilot 2 rated it a CHR 5 his first attempt and a CHR 4 for his second attempt. Pilot 3 gave the test point a CHR of 6. This same logic was used for the PIO rating as well. Finally, the asterisk means that a plot of this specific test point is shown below.

2. Graphical results from a single evaluation of a test point. The time history of the pilot longitudinal tracking and a histogram of rate limit is provided. It was noticed just prior to the release of this report that there was a time discrepancy. Hence the time histories are off by approximately 10 percent. The Flight Dynamics Directorate (Flying Qualities Section) is the point of contact for all corrections to time-history data.

3. A catalog of all pilot comments from the in-flight data. Every pilot comment has been translated into these tables. All pilot comments are organized per pilot and flight evaluation. Once again, the asterisk denotes that a plot of that test point appears on the previous page.

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Table C1
TEST POINTS FLOWN IN THE NT-33A

No.	Test Condition	Page	No.	Test Condition	Page
1	2D, 10 degrees per second, DIS	46	19	2P, 10 degrees per second, SOS	82
2	2D, 20 degrees per second, DIS	48	20	2P, 20 degrees per second, SOS	84
3	2D, 30 degrees per second, DIS	50	21	2P, 30 degrees per second, SOS	86
4	2D, 40 degrees per second, DIS	52	22	2P, 40 degrees per second, SOS	88
5	2D, 50 degrees per second, DIS	54	23	2P, 50 degrees per second, SOS	90
6	2D, 157 degrees per second, DIS	56	24	2P, 157 degrees per second, SOS	92
7	2D, 10 degrees per second, SOS	58	25	2DU, 20 degrees per second, DIS	94
8	2D, 20 degrees per second, SOS	60	26	2DU, 30 degrees per second, DIS	96
9	2D, 30 degrees per second, SOS	62	27	2DU, 40 degrees per second, DIS	98
10	2D, 40 degrees per second, SOS	64	28	2DU, 50 degrees per second, DIS	100
11	2D, 50 degrees per second, SOS	66	29	2DU, 60 degrees per second, DIS	102
12	2D, 157 degrees per second, SOS	68	30	2DU, 157 degrees per second, DIS	104
13	2P, 10 degrees per second, DIS	70	31	2DU, 20 degrees per second, SOS	106
14	2P, 20 degrees per second, DIS	72	32	2DU, 30 degrees per second, SOS	108
15	2P, 30 degrees per second, DIS	74	33	2DU, 40 degrees per second, SOS	110
16	2P, 40 degrees per second, DIS	76	34	2DU, 50 degrees per second, SOS	112
17	2P, 50 degrees per second, DIS	78	35	2DU, 60 degrees per second, SOS	114
18	2P, 157 degrees per second, DIS	80	36	2DU, 157 degrees per second, SOS	116

Notes: 1. DIS - discrete task
2. SOS - sum-of-sines task

Table C2

SUMMARY 2D, RATE LIMIT OF 10 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2D	Rate Limit: 10 degrees per second	Tracking Task: Discrete
Cooper-Harper Ratings: 5 ‖ 5/4 ‖ 6*	PIO Ratings: 3 ‖ 3/2 ‖ 3*	

<u>Overall Evaluation</u>

Both the initial and steady-state response were rated slow to responsive. The aircraft was considered predictable for most of the task, but the pilots noticed overshoots when the input was large during the gross acquisition. All evaluations agreed the gross acquisition was difficult with this configuration. However, the aircraft response was such that the fine tracking ability was not objectionable. Each evaluation achieved the desired performance criteria of keeping the target within the 10-mile reticle. The control harmony was noted to be worse at higher g and two evaluations considered this aircraft to have poor control harmony. Pilot compensation was minimal for fine tracking but moderate for gross acquisition. The pilot workload was tolerable in three out of the four evaluations. In all four evaluations of this configuration, no PIOs resulted. Overall comments from the pilots were this configuration tracks well but in gross acquisition where the target makes a step input, objectionable small oscillations about the target developed. This was considered a Level 2 aircraft which produces undesirable motion compromising task performance.

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. A "/" separates multiple ratings by the same pilot.
3. An "*" indicates test point plotted in Figure C1.

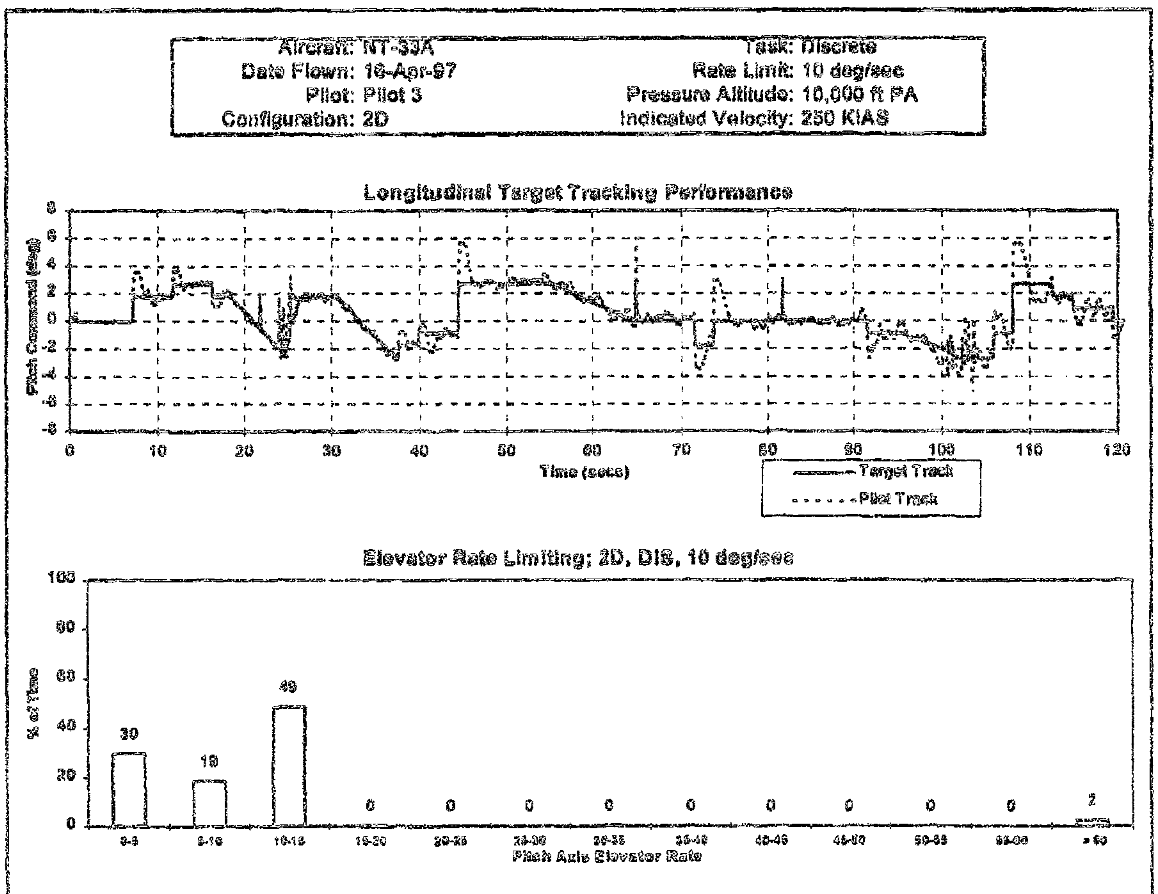

Figure C1 Representative Flight Test Result 2D, Rate Limit of 10 Degrees Per Second, Discrete Task, Pilot 3

Table C3

PILOT COMMENTS FOR 2D, RATE LIMIT OF 10 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2D	Rate Limit: 10 degrees per second		Tracking Task: Discrete
Pilot - Sortie(s)	Pilot 1 - 4	Pilot 2 - 5/7	Pilot 3 - 6*
Cooper-Harper Ratings	5	5/4	6
PIO Ratings	3	3/2	3
AIRCRAFT			
Initial Response	Slow to responsive	Slow/Responsive	Responsive
Steady-State Response	Responsive	Slow/Slow	Slow
Predictable	Yes	Yes during fine tracking and no during gross acquisition/Yes	No (two-thirds of the time overshoots occurred)
Gross Acquisition	Difficult (high gain and large amplitude)	Difficult/Easy for small acquisition Difficult for large acquisition	Difficult
Fine Tracking	Desired	Desired/Desired	Desired
PILOT INTERFACE			
Control Harmony	Good (worse at high-g)	Poor to good/Good	Poor
Stick Forces	Medium	Medium/Medium	High
Compensation	Minimal (Fine Tracking) Moderate (Gross Acquisition)	Considerable/ Mostly minimal, Moderate (for Gross Acquisition)	Moderate
Workload	Tolerable	Tolerable/ Minimal to tolerable	Tolerable
Was there a PIO? Easily Induced?	No No	No/No No/No	No No
COMMENTS			
Good Characteristics	Nice fine track with small bobbles. Good feeling airplane.	Tracks well under g, acquisition good under positive-g/No oscillations under tracking low and high g, reverses well, no great pitch-up, unloads well during reverse	None.
Bad Characteristics	Constant annoying pitch oscillations. Aggressive capture led to fairly large overshoots.	Small oscillations about target, sluggish steady state, predictability poor, sluggish to respond to negative-g, desirable performance criteria achieved but gross acquisition was objectionable/Large overshoot with gross acquisition, slow response to negative-g acquisition, sluggish steady-state response	Initial response springy, steady-state response slow The configuration does not allow the pilot to track high gain because of slow steady-state response. Two to three oscillations tend to develop during gross acquisition.

Notes: 1. A "/" separates multiple ratings by the same pilot.
2. An "*" indicates test point plotted in Figure C1.

Table C4
SUMMARY 2D, RATE LIMIT OF 20 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2D	Rate Limit: 20 degrees per second	Tracking Task: Discrete
Cooper-Harper Ratings: 2* ‖ 3 ‖ 2	PIO Ratings: 2* ‖ 2 ‖ 2	
Overall Evaluation	This configuration had responsive initial and steady-state response. The aircraft was predictable making the gross acquisition task easy. All three evaluation pilots were able to achieve the desired performance criteria. The control harmony was good with medium stick forces. The pilot compensation and workload were rated minimal by two of the three pilots. In all three evaluations, no PIOs occurred. Some pilot comments include: "very nice flying airplane," "tracks well during reversal," "precise tracker," "little sluggish during negative-g acquisitions," and "small overshoots (bobbles) of target during large steps and under g." This was considered a Level 1 aircraft with no tendency for PIO.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C2.

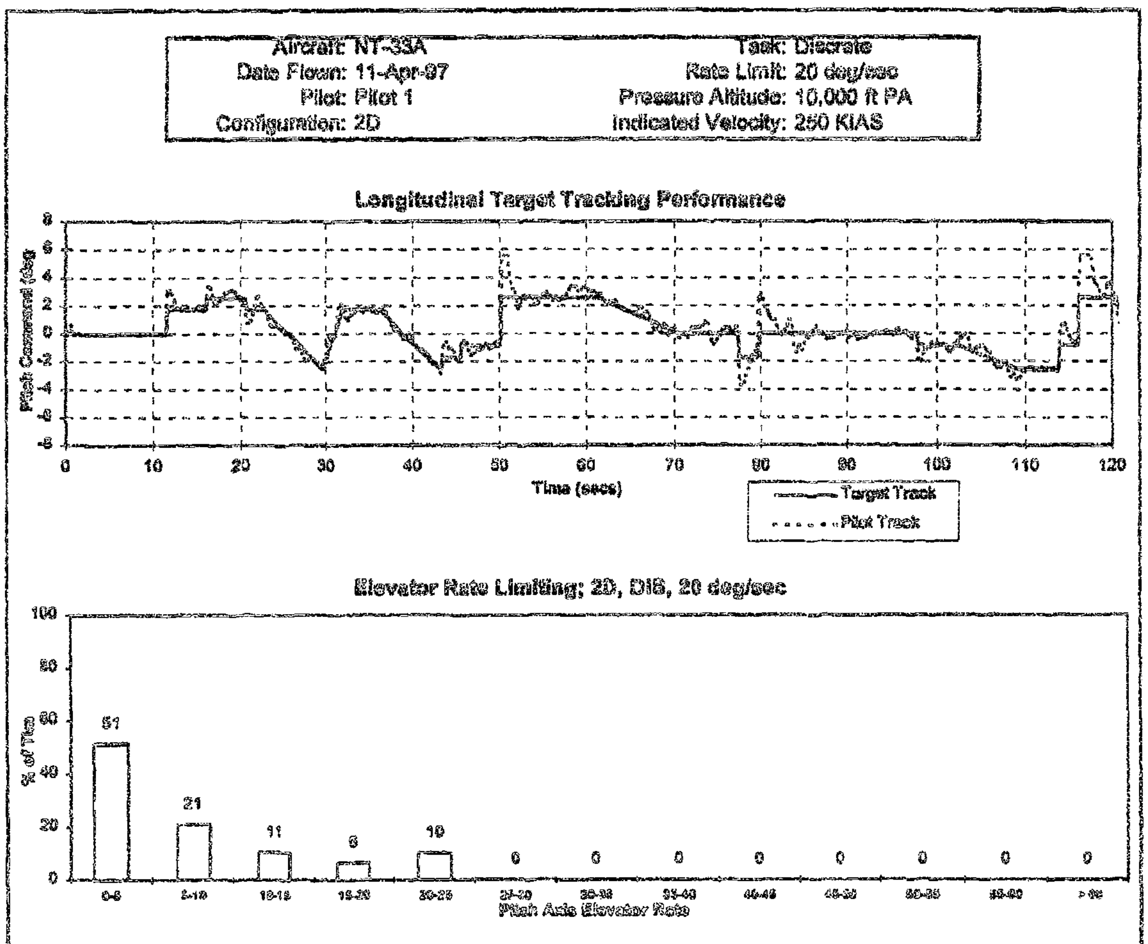

Figure C2 Representative Flight Test Result 2D, Rate Limit of 20 Degrees Per Second, Discrete Task, Pilot 1

Table C5
PILOT COMMENTS FOR 2D, RATE LIMIT OF 20 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2D	Rate Limit: 20 degrees per second		Tracking Task: Discrete
Pilot - Sortie(s)	Pilot 1 - 1*	Pilot 2 - 5	Pilot 3 - 3
Cooper-Harper Ratings	2	3	2
PIO Ratings	2	2	2
AIRCRAFT			
Initial Response	Responsive	Responsive	Responsive
Steady-State Response	Responsive	Responsive	Responsive
Predictable	Yes	Yes	Yes
Gross Acquisition	Easy	Easy	Easy
Fine Tracking	Desired ("Outstanding")	Desired	Desired
PILOT INTERFACE			
Control Harmony	Good	Good	Good
Stick Forces	Medium	Medium	Medium (15 lb)
Compensation	Moderate	Moderate	Moderate
Workload	Minimal	Minimal	Tolerable to minimum
Was there a PIO? Easily Induced?	No No	No No	No No
COMMENTS			
Good Characteristics	Very nice flying airplane	Quick initial response, gross acquisition good, overshoots within desired criteria, tracks well during reversal	Good aircraft response, Easy to gross and fine track, Precise tracker
Bad Characteristics	None.	Small pitch bobble about target for low g, little sluggish during negative-g acquisition	Two small overshoots of the target during large steps and under g

Note: An "*" indicates test point plotted in Figure C2.

Table C6

SUMMARY 2D, RATE LIMIT OF 30 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2D	Rate Limit: 30 degrees per second	Tracking Task: Discrete
Cooper-Harper Ratings: 2 ‖ 2* ‖ 1	PIO Ratings: 2 ‖ 1* ‖ 1	
Overall Evaluation	This configuration had responsive initial and steady-state response. The aircraft was predictable making the gross acquisition task easy. All three evaluation pilots were able to achieve the desired performance criteria. The control harmony was good with medium stick forces. The pilot compensation and workload were rated minimal. In all three evaluations, no PIOs occurred. Some pilot comments include: "nice airplane," "no tendency to oscillate about the target," "pitch captures easy," "predictable," "very good tracker." This was considered a Level 1 aircraft with no tendency for PIO.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C3.

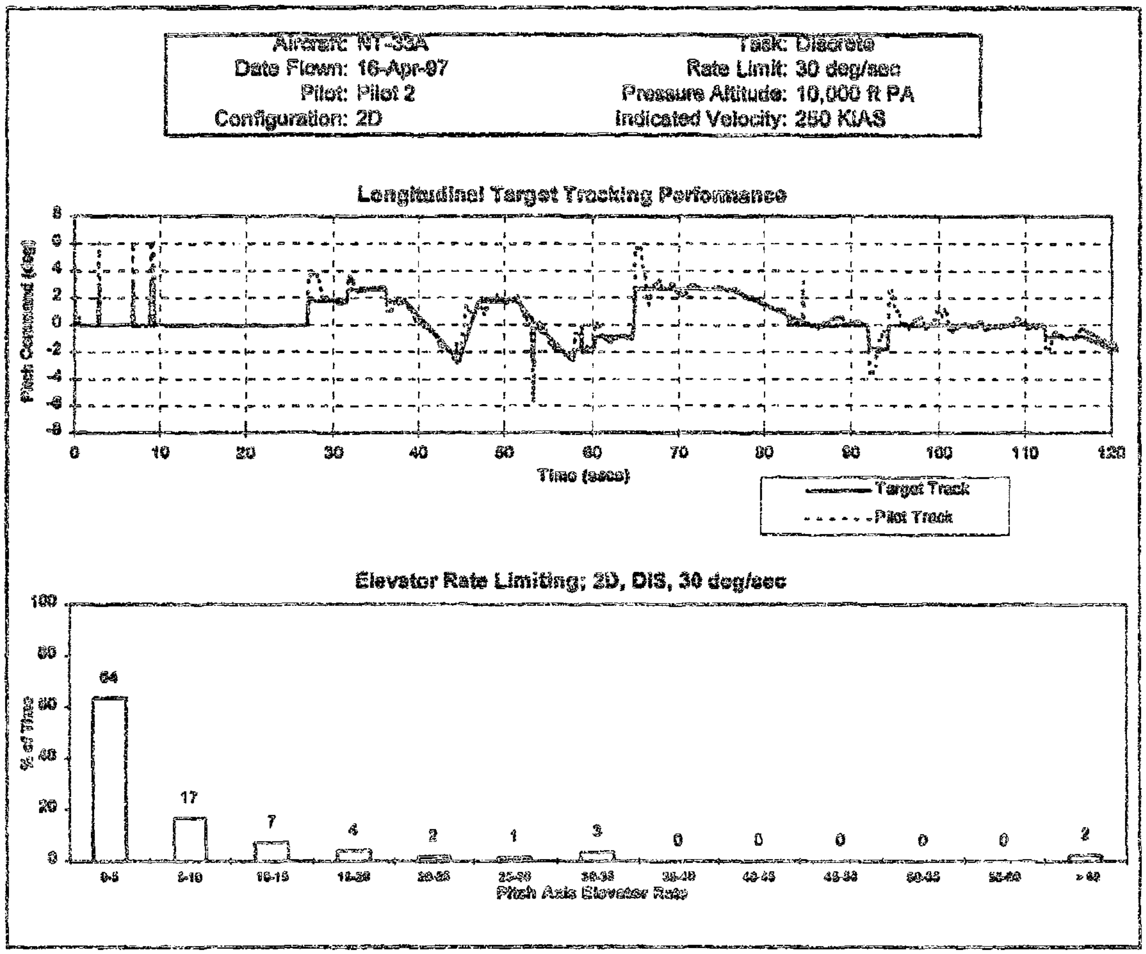

Figure C3 Representative Flight Test Result 2D, Rate Limit of 30 Degrees Per Second, Discrete Task, Pilot 2

Table C7
PILOT COMMENTS FOR 2D, RATE LIMIT OF 30 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2D	Rate Limit: 30 degrees per second		Tracking Task: Discrete
Pilot - Sortie(s)	Pilot 1 - 9	Pilot 2 - 7*	Pilot 3 - 8
Cooper-Harper Ratings	2	2	1
PIO Ratings	2	1	1
AIRCRAFT			
Initial Response	Responsive	Responsive	Responsive
Steady-State Response	Responsive	Responsive	Responsive
Predictable	Yes	Yes	Yes
Gross Acquisition	Easy	Easy	Easy
Fine Tracking	Desired	Desired criteria achieved	Desired
PILOT INTERFACE			
Control Harmony	Good	Good to Excellent	Good
Stick Forces	Low	Medium	Medium
Compensation	Minimal	Minimal	Minimal
Workload	Minimal	Minimal	Minimal
Was there a PIO? Easily Induced?	No No	No No	No No
COMMENTS			
Good Characteristics	Open-loop was good feeling airplane	Nice airplane, no tendency to oscillate about the target, negative-g pitch captures easy, control harmony good, good reversals	Pleasantly quick initial and steady-state response, predictable, very good tracker
Bad Characteristics	Control harmony problem was noticeable but not too objectionable	None	One pitch rate oscillation under g (not objectionable)

Note: An "*" indicates test point plotted in Figure C3.

Table C8
SUMMARY 2D, RATE LIMIT OF 40 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2D	Rate Limit: 40 degrees per second	Tracking Task: Discrete
Cooper-Harper Ratings: 3 ‖ 5*/2/4 ‖ 1/2	PIO Ratings: 2 ‖ 3*/1/2 ‖ 1/2	
Overall Evaluation	The initial and steady-state response were rated as responsive five out of six evaluations. The aircraft was predictable making the gross acquisition task easy. The pilots were able to achieve the desired performance criteria during fine tracking. The control harmony was good with medium stick forces. The pilot compensation was minimal to moderate, and the workload was minimal to tolerable. In all six evaluations, no PIOs occurred. Some pilot comments include: "Solid, comfortable feel," "it doesn't surprise pilot," "excellent initial capture," "control harmony increased some workload rolling out of elevated-g task," "springy and abrupt ... requiring extensive compensation with gross acquisition." This aircraft was a border line Level 1/Level 2 airplane with no tendency to develop PIO.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. A "/" separates multiple ratings by the same pilot.
3. An "*" indicates test point plotted in Figure C4.

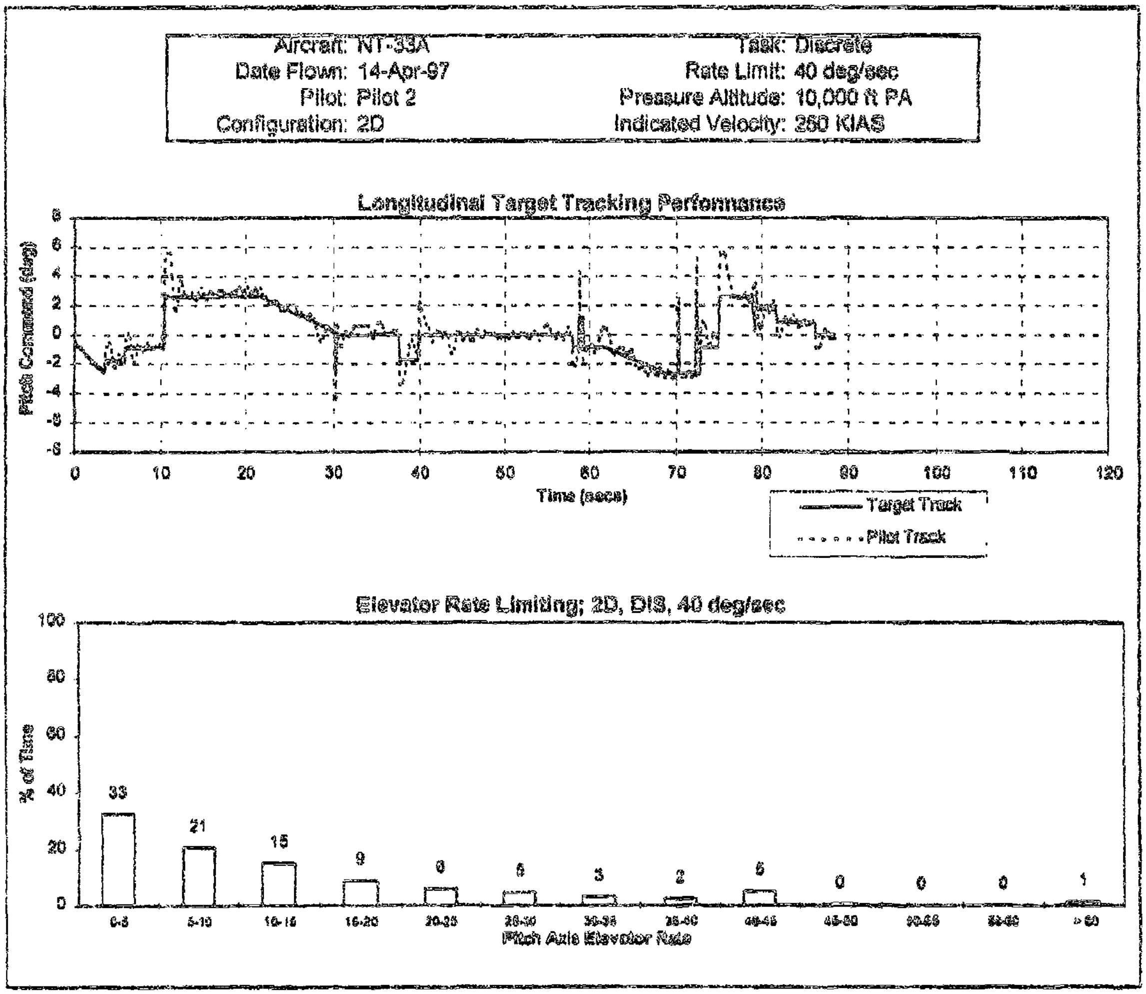

Figure C4 Representative Flight Test Result 2D, Rate Limit of 40 Degrees Per Second, Discrete Task, Pilot 2

Table C9
PILOT COMMENTS FOR 2D, RATE LIMIT OF 40 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2D	Rate Limit: 40 degrees per second	Tracking Task: Discrete	
Pilot - Sortie(s)	Pilot 1 - 1	Pilot 2 - 2*/5/7	Pilot 3 - 3/6
Cooper-Harper Ratings	3 (due to harmony issue)	5/2/4	1/2
PIO Ratings	2	3/1/2	1/2
AIRCRAFT			
Initial Response	Responsive	Responsive/Responsive/ Fast	Responsive/Responsive
Steady-State Response	Responsive	Responsive/Responsive/ Responsive	Responsive/Responsive
Predictable	Yes	Yes/Yes/Yes	Yes/Yes
Gross Acquisition	Easy	Easy/Easy/Easy for small acquisition, difficult with large acquisition	Easy/Easy
Fine Tracking	Desired	Adequate/Desired/Desired	Desired/Desired
PILOT INTERFACE			
Control Harmony	Good at elevated-g, excellent at low-g	Good/Good/Good	Good/Good
Stick Forces	Medium	Medium/Medium/Medium	Medium/Medium
Compensation	Minimal	Moderate/Minimal/ Minimal to moderate	Minimal/Moderate
Workload	Minimal	Tolerable/Minimal/ Minimal to tolerable	Tolerable/Tolerable
Was there a PIO? Easily Induced?	No No	No/No/No No/No/No	No/No No/No
COMMENTS			
Good Characteristics	Solid, comfortable feel, excellent initial capture	Gross acquisition good, mild oscillations when stabilizing to fine tracking, compromises performance/Nice airplane, tracks well under g, no oscillations about target, predictable, minimal compensation/No oscillations about target during tracking	Very good configuration, it doesn't surprise the pilot. Tracking could be done confidently/ Tracking is good
Bad Characteristics	Control harmony problem increased workload rolling out of elevated-g task	Bobble in pitch, small oscillations about target when not under g, difficult to stabilize on target/Small pitch up with reversal under g, stick feels little heavy with gross acquisition and extensive tracking/Nose-up with reversal, springy and abrupt with inputs, little jumpy extensive compensation with gross acquisition	None/Two small oscillations during aggressive big pulls and g's, no PIO but undesirable motions occurred

Notes: 1. A "/" separates multiple ratings by the same pilot.
2. An "*" indicates test point plotted in Figure C4.

Table C10
SUMMARY 2D, RATE LIMIT OF 50 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2D	Rate Limit: 50 degrees per second	Tracking Task: Discrete
Cooper-Harper Ratings: 4 ‖ 2 ‖ 4*	PIO Ratings: 2 ‖ 1 ‖ 2*	
Overall Evaluation	The initial and steady-state response were rated as responsive in each evaluation. The aircraft was predictable making the gross acquisition task easy. The pilots were able to achieve the desired performance criteria during fine tracking. The control harmony was good with medium stick forces and one pilot noticed the forces lightened at elevated g. The pilot compensation was minimal to moderate, and the workload was minimal to tolerable. In all three evaluations, no PIOs occurred. Some pilot comments include: "good feeling airplane - solid," "aggressiveness does not influence task performance," "two to three overshoots (during gross acquisition)," and "annoying stick force gradient." This aircraft was a border line Level 1/Level 2 airplane with no tendency to develop PIO.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C5.

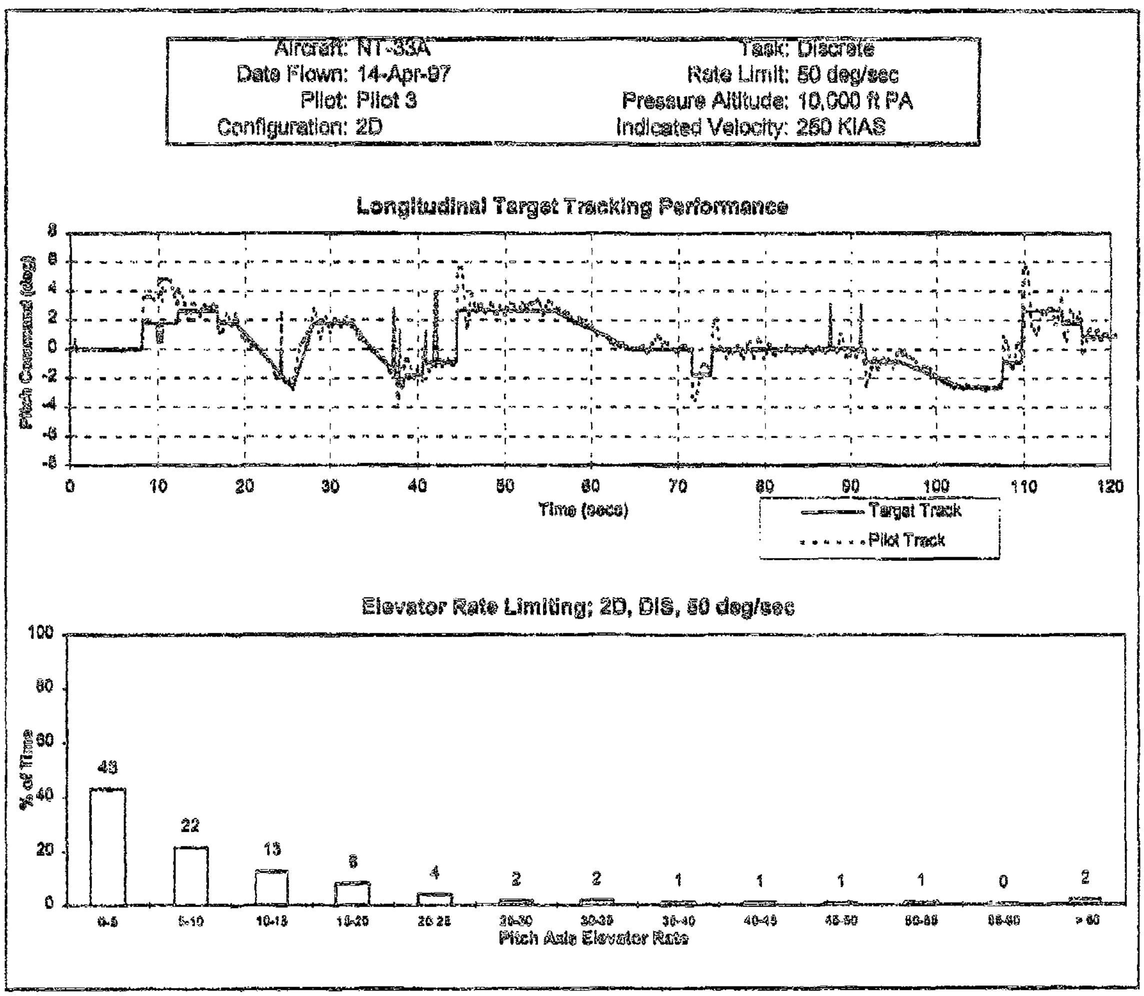

Figure C5 Representative Flight Test Result 2D, Rate Limit of 50 Degrees Per Second, Discrete Task, Pilot 3

Table C11
PILOT COMMENTS FOR 2D, RATE LIMIT OF 50 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2D	Rate Limit: 50 degrees per second		Tracking Task: Discrete
Pilot -Sortie(s)	Pilot 1 - 1	Pilot 2 - 2	Pilot 3 - 3*
Cooper-Harper Ratings	4 (due to force gradient; close to 3)	2	4
PIO Ratings	2	1	2
AIRCRAFT			
Initial Response	Responsive	Responsive	Responsive
Steady-State Response	Responsive	Responsive	Responsive
Predictable	Yes	Yes	Yes
Gross Acquisition	Easy (one overshoot)	Easy	Easy
Fine Tracking	Desired	Desired	Desired
PILOT INTERFACE			
Control Harmony	Good for greater than 1.5 g Excellent for 1.5 g's	Good	Good
Stick Forces	Low at high-g	Medium	Medium
Compensation	Minimal at high-g	Minimal	Moderate
Workload	Minimal	Minimal to Tolerable	Tolerable
Was there a PIO? Easily Induced?	No No	No No	No No
COMMENTS			
Good Characteristics	Good feeling airplane - solid	Really nice airplane, minimal compensation, no tendency to oscillate, very predictable, gross acquisition was good, good tracking under g, no pitch oscillations, rolls good under g, minimal compensation for back stick	Aggressiveness does not influence task performance, pretty good tracker
Bad Characteristics	Control harmony is a problem, maneuvering around F_s break point is annoying, compensation was generally in response to F_s gradient	One to two stop short of target with gross acquisition, compensation required with progression in task	Two to three overshoots

Note: An "*" indicates test point plotted in Figure C5.

Table C12
SUMMARY 2D, RATE LIMIT OF 157 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2D	Rate Limit: 157 degrees per second	Tracking Task: Discrete
Cooper-Harper Ratings: 2 ‖ - ‖ 4*	PIO Ratings: 2 ‖ - ‖ 2*	
Overall Evaluation	The initial response was responsive, but the steady-state response was fast making the aircraft a little "jerky." The aircraft was predictable making the gross acquisition task easy. The pilots were able to achieve desired performance criteria. The control harmony was good with medium stick force. The pilot compensation was moderate and workload tolerable. In the two evaluations, no PIO occurred. Pilot comment included: "pitch rate oscillations were quick and surprising - minor but annoying deficiency." This aircraft configuration was rated as Level 2 airplane with no tendency to PIO.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3. 3. A "-" indicates no rating was given.
2. An "*" indicates test point plotted in Figure C6.

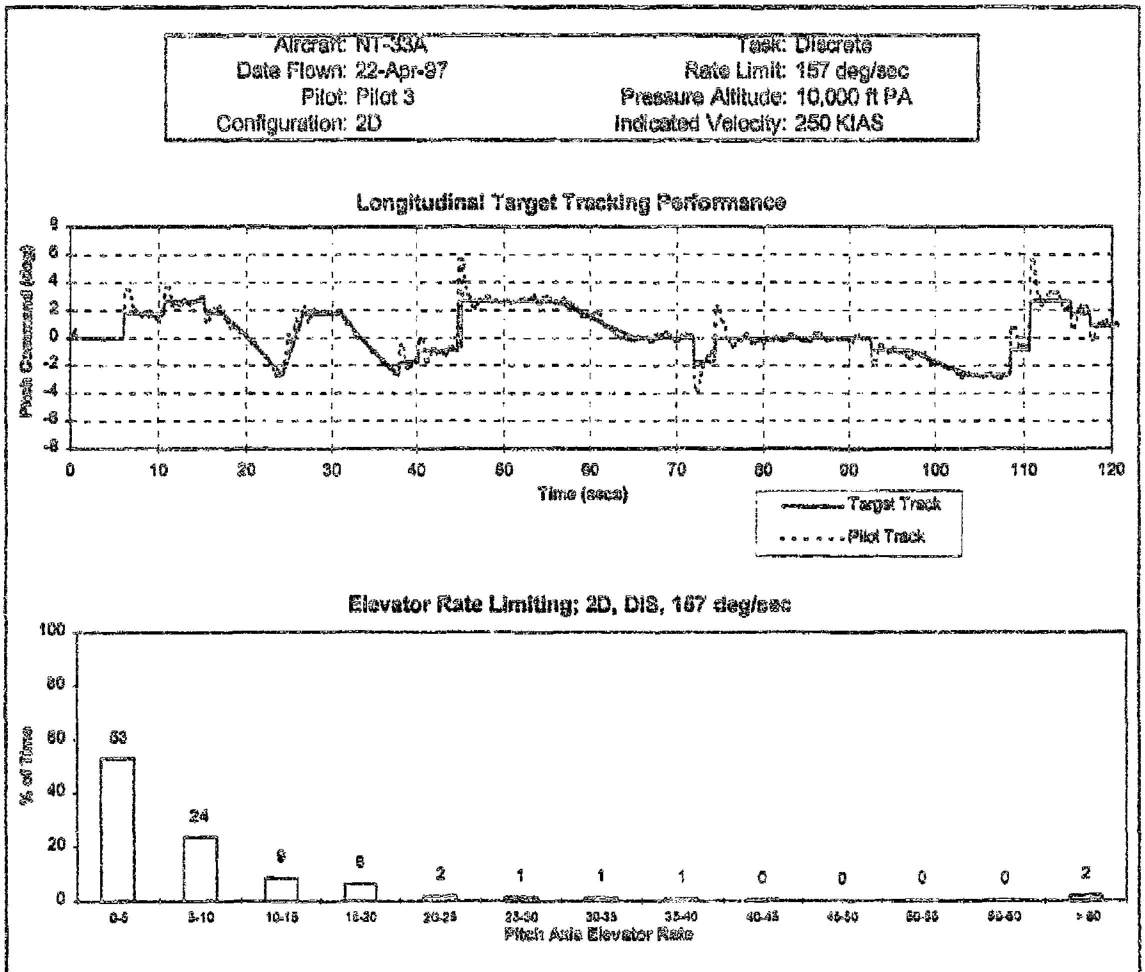

Figure C6 Representative Flight Test Result 2D, Rate Limit of 157 Degrees Per Second, Discrete Task, Pilot 3

Table C13
PILOT COMMENTS FOR 2D, RATE LIMIT OF 157 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2D	Rate Limit: 180 degrees per second		Tracking Task: Discrete
Pilot- Sortie(s)	Pilot 1 - 9	Pilot 2 - Not Flown	Pilot 3 - 8*
Cooper-Harper Ratings	2	Not Flown	4
PIO Ratings	2	Not Flown	2
AIRCRAFT			
Initial Response	Responsive (very good)	N/A	Responsive
Steady-State Response	Responsive	N/A	Fast
Predictable	Yes (one of the best)	N/A	Yes
Gross Acquisition	Easy	N/A	Easy
Fine Tracking	Desired	N/A	Desired
PILOT INTERFACE			
Control Harmony	Good (heavy stick at high-g)	N/A	Good
Stick Forces	Medium	N/A	Medium
Compensation	Minimal	N/A	Moderate
Workload	Minimal	N/A	Tolerable
Was there a PIO? Easily Induced?	No No	N/A	No No
COMMENTS			
Good Characteristics	One of the best configurations so far.	N/A	None
Bad Characteristics	Only mild unpleasantness due to control harmony.	N/A	One big pulls under g, pitch rate oscillations (2 to 3) that were quick and surprising (minor but annoying deficiencies)

Notes: 1. An "*" indicates test point plotted in Figure C6.
2. N/A - not applicable.

Table C14
SUMMARY 2D, RATE LIMIT OF 10 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2D	Rate Limit: 10 degrees per second	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 5 ‖ 5* ‖ 7	PIO Ratings: 3 ‖ 3* ‖ 4	
Overall Evaluation	The initial and steady-state response was considered slow to responsive. One pilot felt the slow responsiveness of the aircraft made it unpredictable and the gross acquisition task difficult. One pilot felt the gross acquisition of small input was easy while the larger inputs made the task difficult. The stick forces were considered medium to high. The pilot compensation was moderate to considerable and the workload ranged from tolerable to slighter intolerable. One pilot felt a small bounded PIO was easy to induce but can be eliminated by reducing pilot gain. This compensation made the tracking task difficult. The other two pilots did not encounter PIO, but felt small bobble about the target making the tracking difficult achieving only adequate performance. Some pilot comments include: "This aircraft was rated as Level 2 bordering Level 3 with tendency for undesirable motions compromising performance task."	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C7.

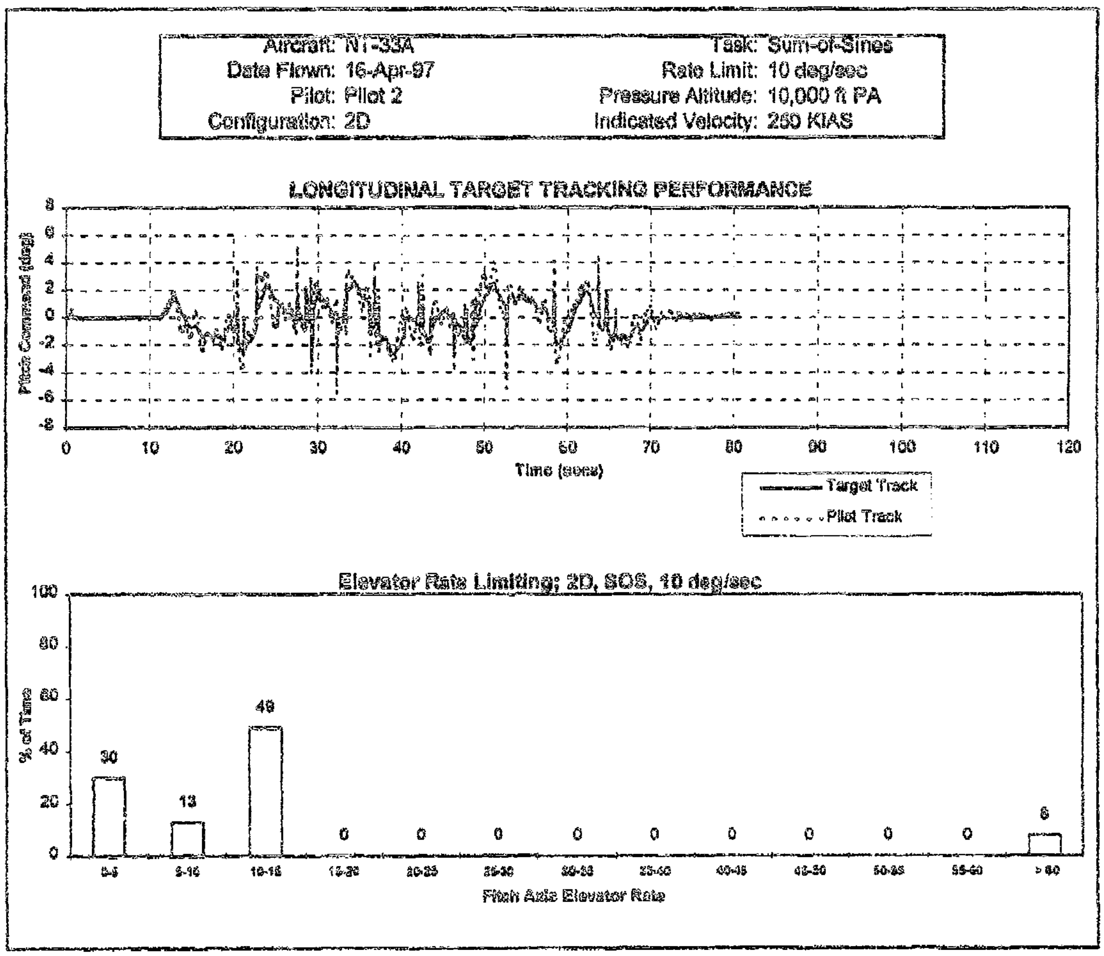

Figure C7 Representative Flight Test Result 2D, Rate Limit of 10 Degrees Per Second, Sum-of-Sines Task, Pilot 2

Table C15
PILOT COMMENTS FOR 2D, RATE LIMIT OF 10 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2D	Rate Limit: 10 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 9	Pilot 2 - 7*	Pilot 3 - 8
Cooper-Harper Ratings	5	5	7
PIO Ratings	3	3	4
AIRCRAFT			
Initial Response	Slow	Responsive	Slow
Steady-State Response	Slow+	Responsive	Slow
Predictable	No	Yes	No
Gross Acquisition	Difficult	Easy (small) Difficult (large)	Difficult
Fine Tracking	Desired	Adequate	N/A
PILOT INTERFACE			
Control Harmony	N/A	N/A	N/A
Stick Forces	High	Medium	Medium to high
Compensation	Minimal (for Fine Tracking) Moderate + (for Goss Acquisition)	Moderate	Moderate to considerable
Workload	Minimal (for Fine Tracking) Tolerable (for Gross Acquisition)	Tolerable	Tolerable to intolerable
Was there a PIO? Easily Induced?	No No	No No	Yes Yes
COMMENTS			
Good Characteristics	None.	N/A	None.
Bad Characteristics	Heavy stick, slow response, led to significant overshoot.	Difficult to stop on target. Small bobble about target.	Slow initial and steady-state response, small bounded PIO eliminated by lowering pilot gains, hard to track the target.

Notes: 1. An "*" indicates test point plotted in Figure C7.
2. N/A - not applicable.

Table C16
SUMMARY 2D, RATE LIMIT OF 20 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2D	Rate Limit: 20 degrees per second	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 4 ‖ 3 ‖ 3*	PIO Ratings: 3 ‖ 2 ‖ 2*	
Overall Evaluation	The initial response was responsive and the steady-state response was responsive to two pilots and fast to one pilot. Overall the aircraft was predictable making gross acquisition task easy and the pilots were able to achieve the desired performance criteria. The stick forces were low to medium. One pilot noted the compensation was minimal for achieving adequate criteria but moderate for achieving the desired criteria. The workload was minimal to tolerable. The three evaluations produced no PIO. Some pilot comments include: "flyable aircraft," "good gross acquisition," "tiny oscillation within the desired criteria," "overall configuration gives the pilot good confidence and tracking," and "mildly oversensitive driving overshoots (bobbles) during the initial capture." This aircraft was rated border Level 1/Level 2 flying qualities airplane with tendency for small undesirable motions which do not affect the task performance.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C8.

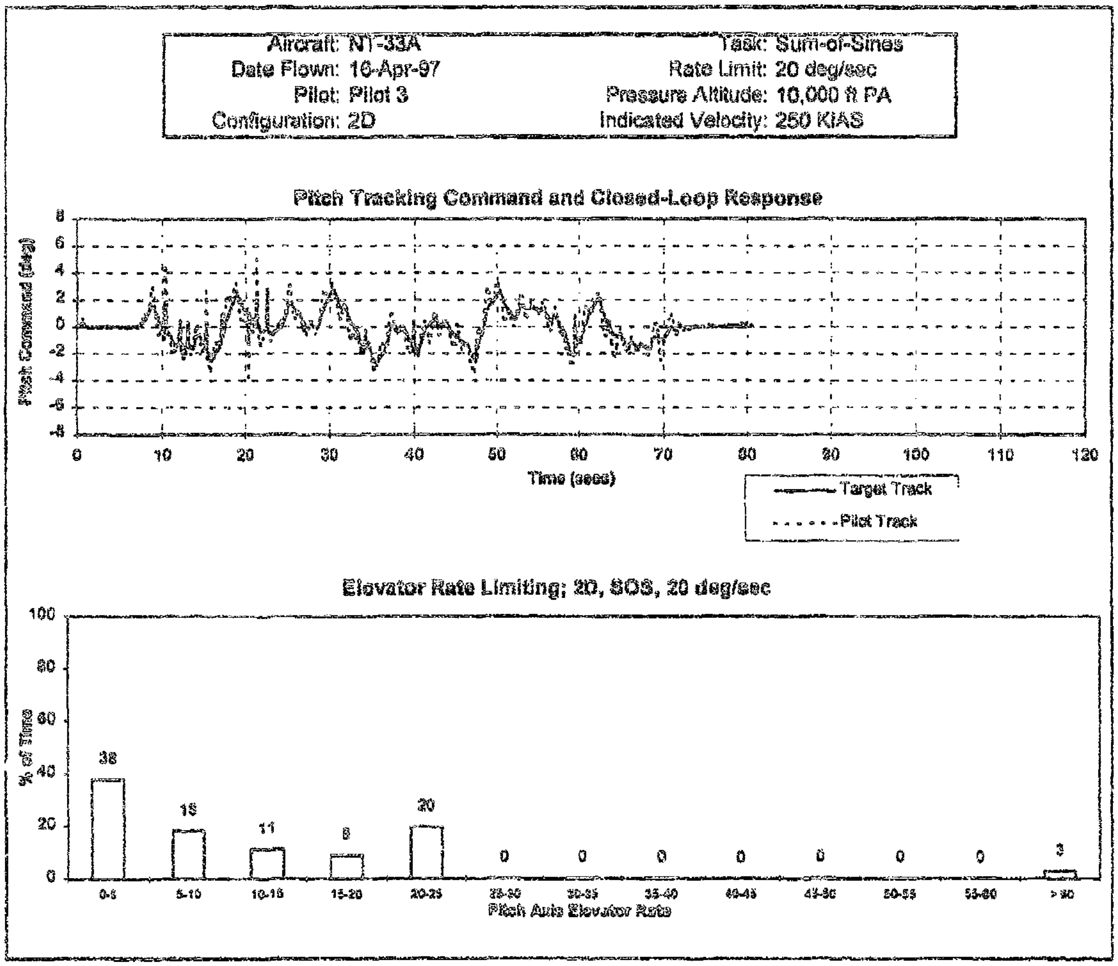

Figure C8 Representative Flight Test Result 2D, Rate Limit of 20 Degrees Per Second, Sum-of-Sines Task, Pilot 3

Table C17
PILOT COMMENTS FOR 2D, RATE LIMIT OF 20 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2D	Rate Limit: 20 degrees per second		Tracking Task: Sum-of-Sines
Pilot- Sortie(s)	Pilot 1 - 1	Pilot 2 - 2	Pilot 3 - 6*
Cooper-Harper Ratings	4	3	3
PIO Ratings	3	2	2
AIRCRAFT			
Initial Response	Responsive	Responsive	Responsive
Steady-State Response	Fast	Responsive	Responsive
Predictable	Yes	Yes	Yes
Gross Acquisition	Easy	Easy	Easy
Fine Tracking	Desired	Desired	Desired
PILOT INTERFACE			
Control Harmony	N/A	N/A	N/A
Stick Forces	Low	Medium	Medium
Compensation	Minimal (adequate) Moderate (desired)	Moderate	Moderate
Workload	Minimal	Tolerable	Tolerable
Was there a PIO? Easily Induced?	No No	No No	No No
COMMENTS			
Good Characteristics	Flyable aircraft and one to two overshoots adequate.	Gross acquisition good. Tracking stable. Tiny oscillations within desired criteria.	Overall configuration gives the pilot good confidence and tracking.
Bad Characteristics	Mildly oversensitive drives one to two overshoots in initial capture. Maybe slightly low stick forces.	Small bobble about target, did not affect tracking. Satisfactory without improvement.	Two to three overshoots about the target when it jumps quickly (mildly unpleasant deficiency).

Notes: 1. An "*" indicates test point plotted in Figure C8.
2. N/A - not applicable.

Table C18
SUMMARY 2D, RATE LIMIT OF 30 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2D	Rate Limit: 30 degrees per second	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 4 ‖ 4/2* ‖ 1	PIO Ratings: 3 ‖ 2/1 ‖ 1	
Overall Evaluation	The initial and steady-state response of this aircraft was responsive. The aircraft was predictable making the gross acquisition task relatively easy. The pilots were able to achieve desired performance criteria. The stick forces were medium. The compensation was minimal for fine tracking but moderate for gross acquisition. The workload was minimal to tolerable. The four evaluations produced no PIO. Some pilot comments include: "good airplane," "negative and positive acquisition was good," "very good tracker insensitive to pilot gains and aggressiveness," "over-sensitivity in pitch generates 1-to-2 overshoots during gross acquisition." This aircraft was rated as Level 1 with the tendency for small bobbling about the target.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3. 3. An "*" indicates test point plotted in Figure C9.
2. A "/" separates multiple ratings by the same pilot.

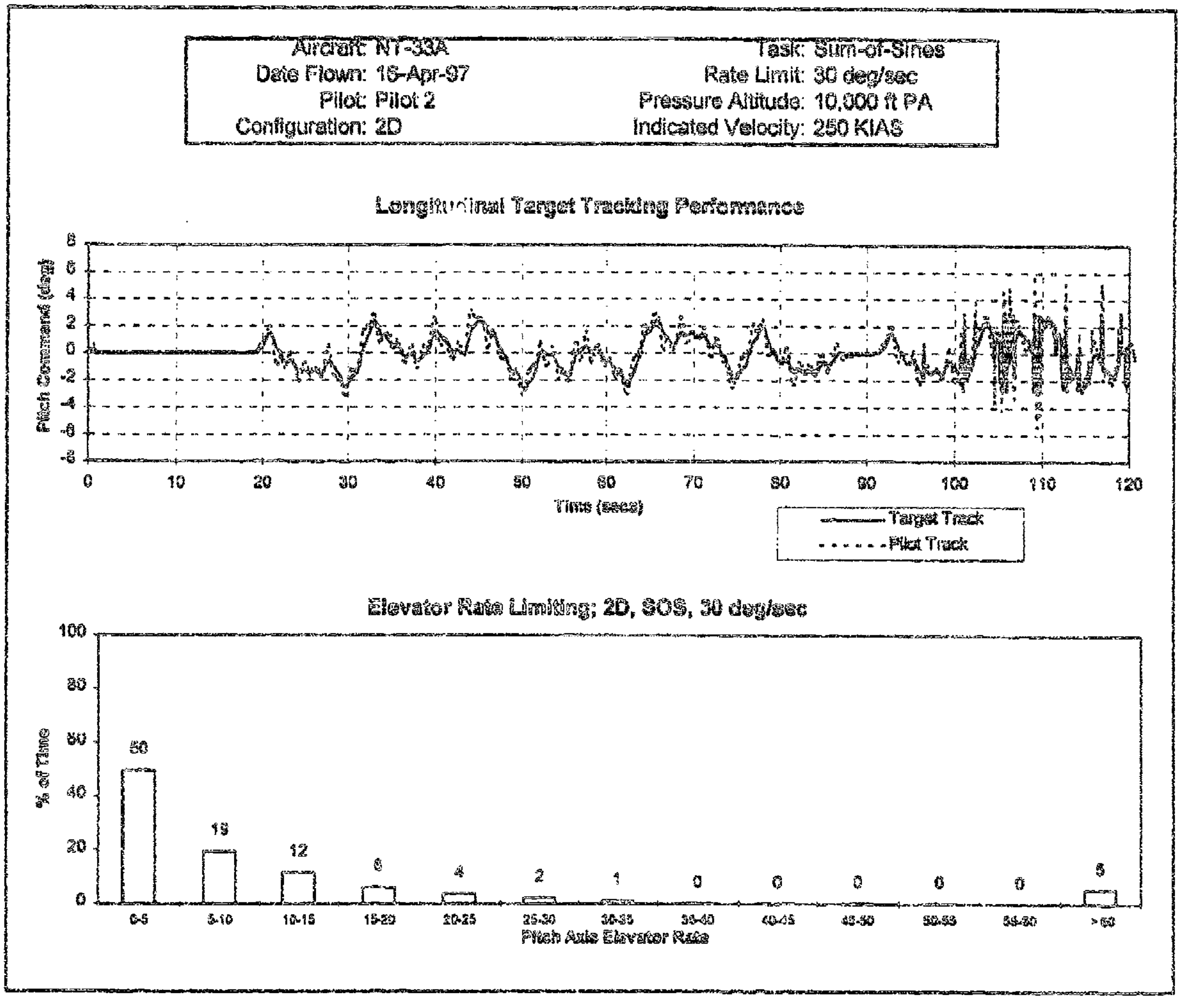

Figure C9 Representative Flight Test Result 2D, Rate Limit of 30 Degrees Per Second, Sum-of-Sines Task, Pilot 2

Table C19

PILOT COMMENTS FOR 2D, RATE LIMIT OF 30 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2D	Rate Limit: 30 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 4	Pilot 2 - 5/7*	Pilot 3 - 6
Cooper-Harper Ratings	4	4/2	1
PIO Ratings	3	2/1	1
AIRCRAFT			
Initial Response	Responsive	Responsive/Responsive	Responsive
Steady-State Response	Responsive	Responsive/Responsive	Responsive
Predictable	Yes	Yes/Yes	Yes
Gross Acquisition	Slightly Difficult	Easy/Easy	Easy
Fine Tracking	Desired	Adequate & Desired/ Desired	Desired
PILOT INTERFACE			
Control Harmony	N/A	N/A	N/A
Stick Forces	Medium	Medium/Medium	Medium
Compensation	Minimal (Fine Tracking) Moderate (Gross Acquisition)	Minimal Moderate/ Minimal	Minimal
Workload	Minimal + (Fine Tracking)	Tolerable/Minimal	Tolerable (Low side)
Was there a PIO? Easily Induced?	No No	No/No No/No	No No
COMMENTS			
Good Characteristics	Good Airplane	More predictable than last test. Desired performance with moderate compensation/Gross acquisition within adequate criteria. Not springy or abrupt like last test point. Negative and positive acquisition good	Steady-state and initial response are quick and well matched. Good predictability. Very good tracker insensitive to pilot gains and aggressiveness.
Bad Characteristics	Over-sensitivity in pitch generated one to two overshoots during gross acquisition. Slightly oversensitive.	Small bobbling about target. Technique to eliminate and compensate.	

Notes: 1. A "/" separates multiple ratings by the same pilot.

2. An "*" indicates test point plotted in Figure C9.

3. N/A - not applicable.

Table C20
SUMMARY 2D, RATE LIMIT OF 40 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2D	Rate Limit: 40 degrees per second	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 4/3 ‖ 4* ‖ 1/2	PIO Ratings: 3/2 ‖ 3* ‖ 1/2	
Overall Evaluation	The initial and steady-state response was considered responsive by all three pilots. The aircraft was predictable making the gross acquisition task easy. The pilots were able to achieve desired performance in four out of five evaluations. The stick forces were medium. The pilot compensation was moderate and the workload ranged minimal to tolerable. In all five evaluations no PIO occurred. This aircraft was rated as Level 2 by two pilots and Level 1 by the third pilot. The aircraft exhibited some undesirable motions which compromised task performance two out of five evaluations.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. A "/" separates multiple ratings by the same pilot.
3. An "*" indicates test point plotted in Figure C10.

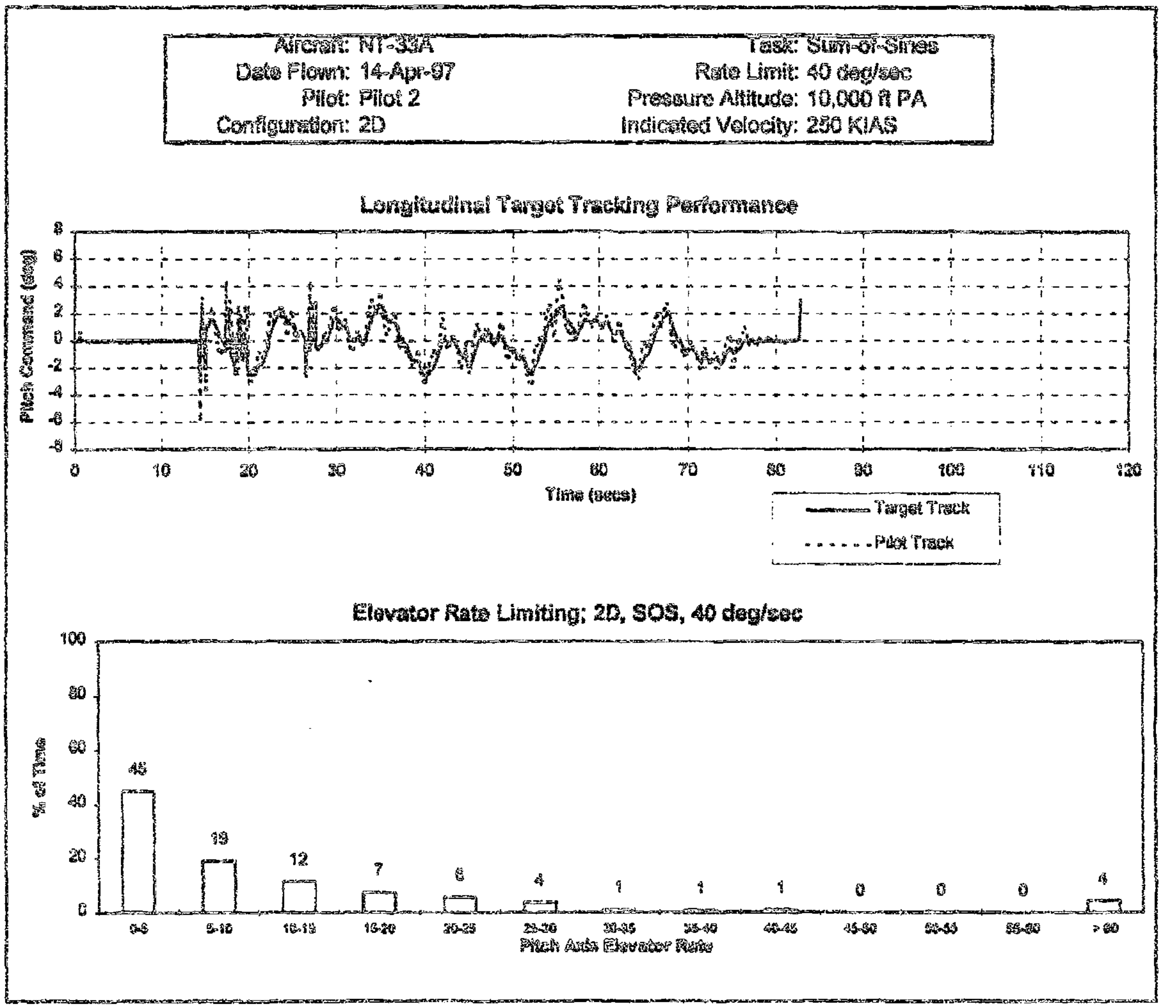

Figure C10 Representative Flight Test Result 2D, Rate Limit of 40 Degrees Per Second, Sum-of-Sines Task, Pilot 2

Table C21
PILOT COMMENTS FOR 2D, RATE LIMIT OF 40 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2D	Rate Limit: 40 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 1/4	Pilot 2 - 2*	Pilot 3 - 3/6/8
Cooper-Harper Ratings	4/3	4	1/2/1
PIO Ratings	3/2	3	1/2/1
AIRCRAFT			
Initial Response	Responsive/Responsive	Responsive	Responsive/Responsive/ Responsive
Steady-State Response	Responsive (high) /Responsive	Responsive	Responsive/Responsive/ Responsive
Predictable	Yes (less than previous)/ Yes	Yes	Yes/Yes/Yes
Gross Acquisition	Easy/Easy (tight spring drove some overshoots)	Easy	Easy/Easy/Easy
Fine Tracking	Desired	Adequate	Desired/Desired/Desired
PILOT INTERFACE			
Control Harmony	Good	Good	N/A
Stick Forces	Low/Medium	Medium	Medium (5 - 10 lb)/ Medium/Medium
Compensation	Minimal/Moderate for Gross Acquisition	Moderate	Moderate/Moderate/ Minimal
Workload	Minimal to tolerable/ Minimal	Tolerable	Tolerable/Tolerable/ Minimal
Was there a PIO? Easily Induced?	No/No No/No	No No	No/No/No No/No/No
COMMENTS			
Good Characteristics	Desired OK with some compensation. Not a bad jet/Solid airplane.	Gross acquisition good.	Very precise tracker. Insensitive to pilot aggressiveness/Precise tracker. Predictable and insensitive to pilot gains/No oscillations. Good tracking even at high pilot gain. Very sharp and quick response.
Bad Characteristics	Not quite as good as previous. Overly sensitive. Not as solid as previous/None	Small oscillations about the target. Task performance compromised slightly. A bit more sensitive than prior run.	Two little overshoots/None/None

Notes: 1. A "/" separates multiple ratings by the same pilot.
2. An "*" indicates test point plotted in Figure C10.
3. N/A - not applicable.

Table C22
SUMMARY 2D, RATE LIMIT OF 50 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2D	Rate Limit: 50 degrees per second	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 4*/3 ‖ 2 ‖ 2	PIO Ratings: 2*/2 ‖ 1 ‖ 1	
Overall Evaluation	The initial and steady-state response was considered responsive by all three pilots. The aircraft was predictable making the gross acquisition task easy. The pilots were able to achieve desired performance. The stick forces were medium. The compensation was minimal and the workload minimal to tolerable. In all four evaluations no PIO occurred. Some pilot comment include: "solid feeling," "insensitive to pilot aggressiveness," "fine tracking," "slightly oversensitive in pitch," and "little jerky initial pitch response." This aircraft was rated as Level 1 with some undesirable pitch which did not affect task performance.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. A "/" separates multiple ratings by the same pilot.
3. An "*" indicates test point plotted in Figure C11.

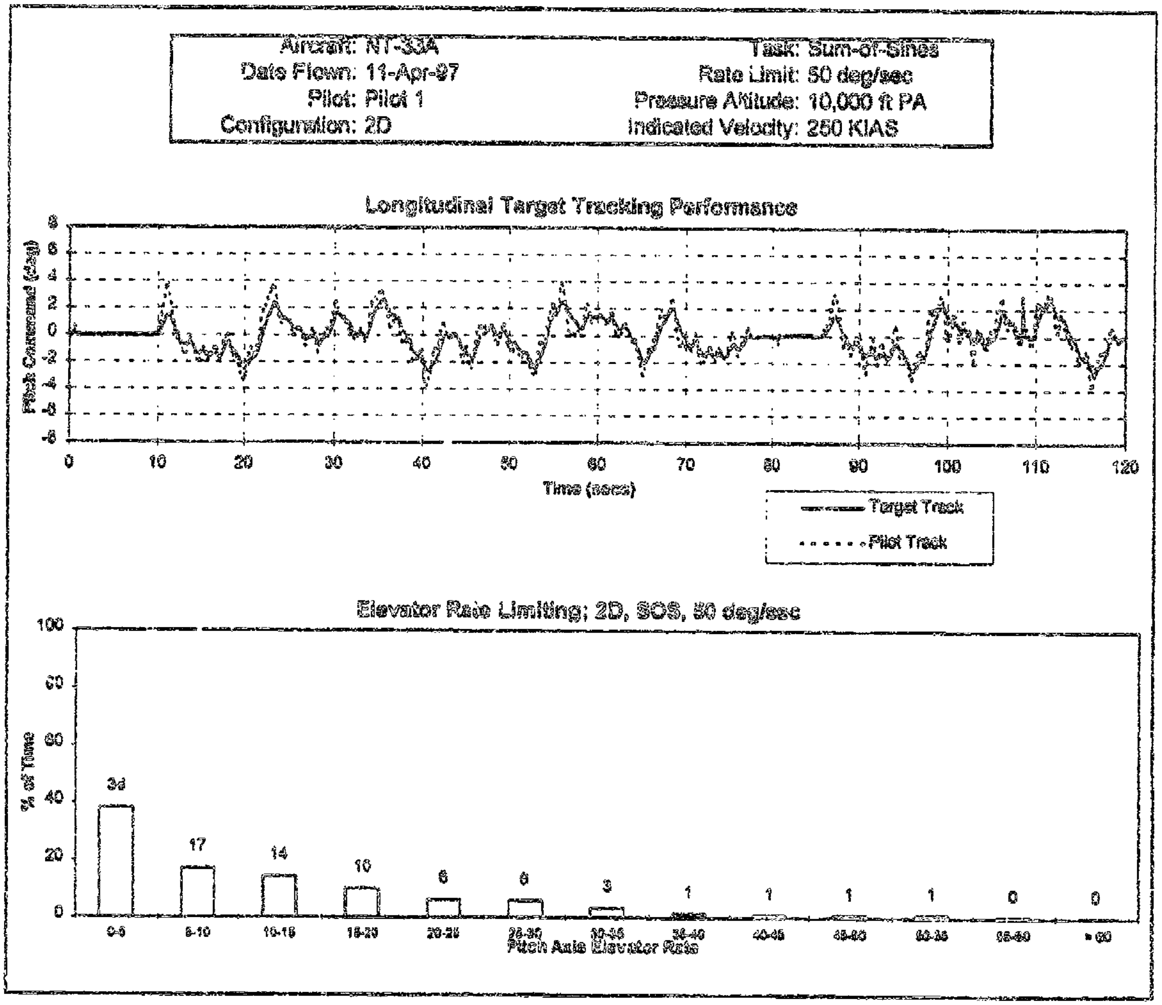

Figure C11 Representative Flight Test Result 2D, Rate Limit of 50 Degrees Per Second, Sum-of-Sines Task, Pilot 1

Table C23
PILOT COMMENTS FOR 2D, RATE LIMIT OF 50 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2D	Rate Limit: 50 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 1*/4	Pilot 2 - 2	Pilot 2 - 3
Cooper-Harper Ratings	4/3	2	2*
PIO Ratings	2/2	1	1
AIRCRAFT			
Initial Response	Responsive/Responsive	Responsive	Responsive
Steady-State Response	Responsive (high)/ Responsive	Responsive	Responsive
Predictable	Yes/Yes	Yes	Yes
Gross Acquisition	Easy/Easy	Easy	Easy
Fine Tracking	Between adequate and desired/Desired	Desired	Desired
PILOT INTERFACE			
Control Harmony	Good/N/A	Good	N/A
Stick Forces	Low/Low + (firm feel)	Medium	Medium
Compensation	Minimal/Minimal	Minimal to tolerable	Moderate
Workload	Minimal/Minimal +	Minimal to tolerable	Moderate
Was there a PIO? Easily Induced?	No/No No/No	No No	No No
COMMENTS			
Good Characteristics	Solid feeling. Fine tracking no problem for desired/One small overshoot then no problem. Nice feeling jet.	No oscillations about target. Nicer than last point. Not having to compensate for the aircraft. No undesirable motions.	Quick pitch response overall. Insensitive to pilot aggressiveness.
Bad Characteristics	Slightly oversensitive in pitch. Drove small overshoots during initial capture/Slightly overly sensitive. Very springy feeling. High frequency short period, but well damped.	N/A	Little jerky initial pitch response.

Notes: 1. A "/" separates multiple ratings by the same pilot.
2. An "*" indicates test point plotted in Figure C11.
3. N/A - not applicable.

Table C24
SUMMARY 2D, RATE LIMIT OF 157 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2D	Rate Limit: 157	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 3 ‖ - ‖ 2*	PIO Ratings: 2 ‖ - ‖ 1*	
Overall Evaluation	The initial response was slow to responsive and the steady-state response was responsive. The aircraft was predictable making the gross acquisition task easy. The pilots were able to achieve desired performance. The stick forces were medium. The compensation was moderate and the workload tolerable. In the two evaluations no PIO occurred. Some pilot comment included: "good tracker," "insensitive to pilot gain," "slight mismatch between initial and steady-state response." This aircraft was rated as Level 1 with no tendency to PIO.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C12.
3. A "-" indicates no rating was given.

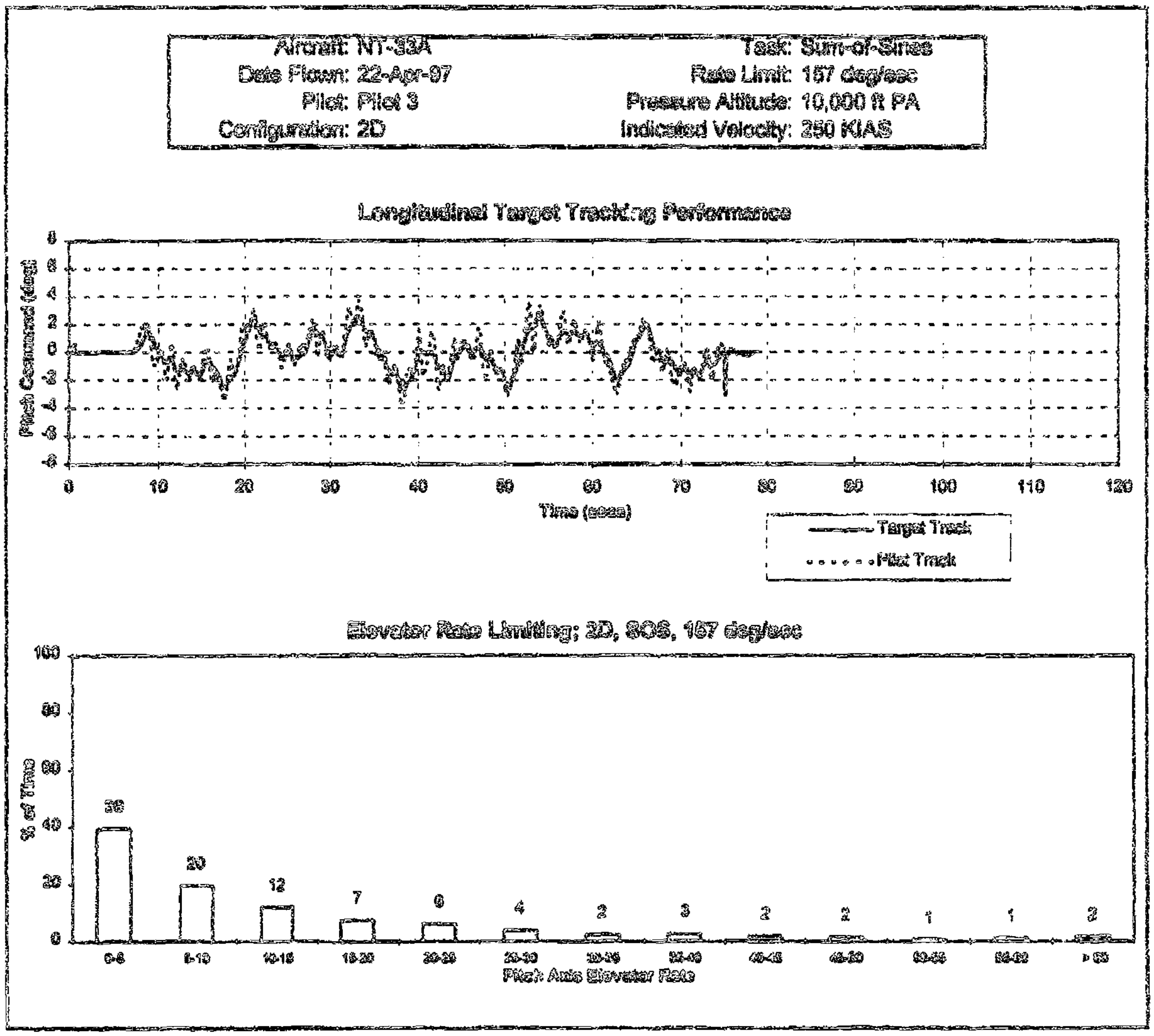

Figure C12 Representative Flight Test Result 2D, Rate Limit of 157 Degrees Per Second, Sum-of-Sines Task, Pilot 3

Table C25
PILOT COMMENTS FOR 2D, RATE LIMIT OF 157 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2D	Rate Limit: 157 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 9	Pilot 2 - Not Flown	Pilot 3 - 8*
Cooper-Harper Ratings	3	Not Flown	2
PIO Ratings	2	Not Flown	1
AIRCRAFT			
Initial Response	Responsive	N/A	Slow
Steady-State Response	Responsive	N/A	Responsive
Predictable	Yes	N/A	Yes
Gross Acquisition	Easy	N/A	Easy
Fine Tracking	Desired	N/A	Desired
PILOT INTERFACE			
Control Harmony	N/A	N/A	N/A
Stick Forces	Low + (comfortable)	N/A	Medium
Compensation	Minimal	N/A	Moderate
Workload	Minimal	N/A	Tolerable
Was there a PIO? Easily Induced?	No No	N/A	No No
COMMENTS			
Good Characteristics	Nice airplane, solid	N/A	Good tracker, insensitive to pilot gains
Bad Characteristics	Small workload increase in gross acquisition due to requirement to compensate for slight over sensitivity in initial capture	N/A	Slight mismatch between the initial and steady-state response (negligible deficiency)

Notes: 1. An "*" indicates test point plotted in Figure C12.
2. N/A - not applicable.

Table C26
SUMMARY 2P, RATE LIMIT OF 10 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2P	Rate Limit: 10 degrees per second	Tracking Task: Discrete
Cooper-Harper Ratings: 6 ‖ 6* ‖ 7		PIO Ratings: 3 ‖ 5* ‖ 3
Overall Evaluation	Initial response was rated to be responsive to slightly fast. Steady-state response was slow. Predictability was poor, with two to three overshoots. The aircraft was described as lightly damped. Gross acquisition was difficult for all evaluation pilots. Fine tracking was adequate to less than adequate requiring considerable compensation for a tolerable workload. Control harmony was poor. No indication of a PIO was noted, though there were undesirable motions which were easily induced. Extensive compensation was required warranting improvement. The aircraft could be felt winding up with large gross acquisitions, with overshoots two times the distance of acquisition distance. Small oscillations about the target made the task difficult during fine tracking. This was considered a Level 3 airplane, with adequate performance not attainable with maximum pilot compensation. Controllability was not in question.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C13.

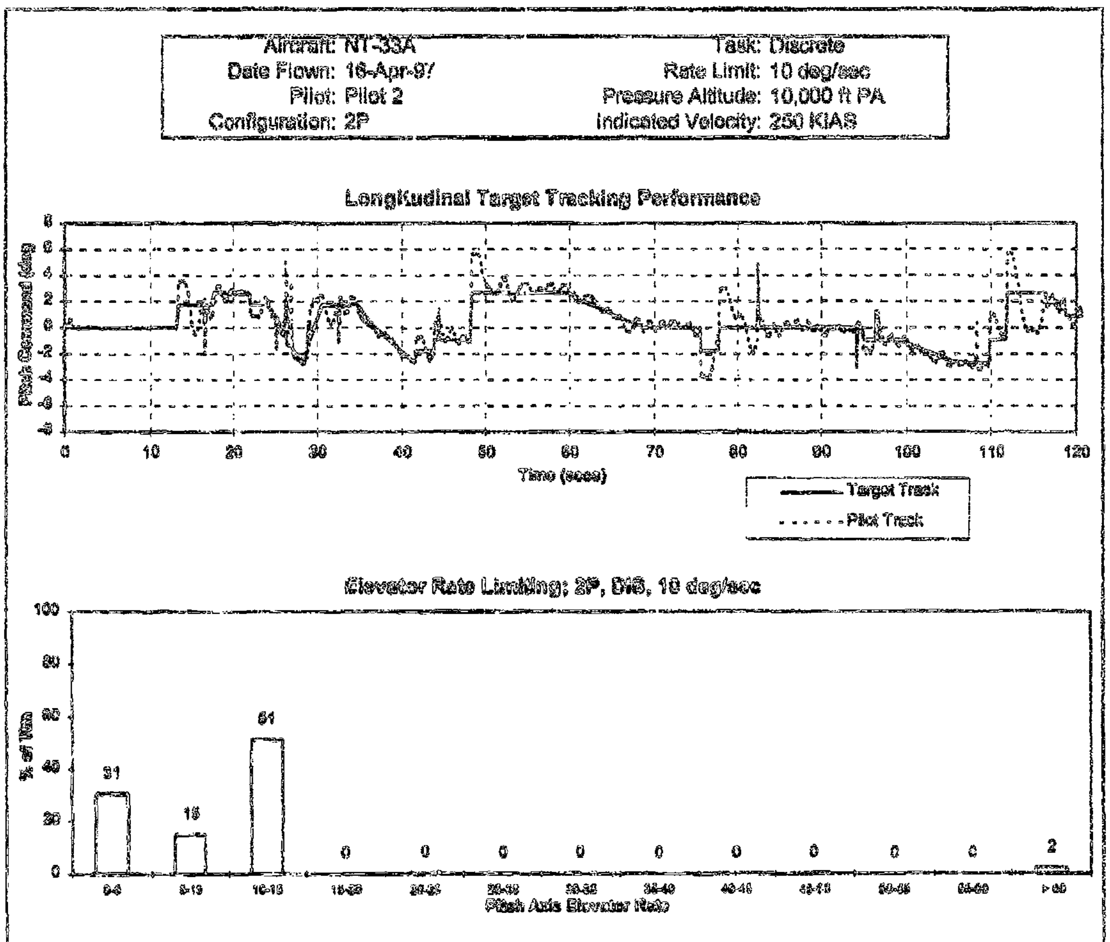

Figure C13 Representative Flight Test Result 2P, Rate Limit of 10 Degrees Per Second, Discrete Task, Pilot 2

Table C27
PILOT COMMENTS FOR 2P, RATE LIMIT OF 10 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2P	Rate Limit: 10 degrees per second		Tracking Task: Discrete
Pilot - Sortie(s)	Pilot 1 - 9	Pilot 2 - 7*	Pilot 3 - 6
Cooper-Harper Ratings	6	6	7
PIO Ratings	3	5	3
AIRCRAFT			
Initial Response	Slow	Fast	Responsive
Steady-State Response	Slow	Slow	Slow
Predictable	No	No; two to three overshoots. Feels lightly damped. Poor.	No
Gross Acquisition	Difficult	Difficult	Difficult
Fine Tracking	Desired	Adequate	N/A
PILOT INTERFACE			
Control Harmony	Poor (light roll/heavy pitch)	Poor	Poor
Stick Forces	Medium to high in pitch	Medium high	High
Compensation	Moderate (for Fine Tracking) Considerable (for Gross Acquisition)	Considerable	Considerable; had to be extra careful and lead a lot the aircraft response.
Workload	Tolerable	Tolerable	Tolerable because the aircraft was so slow
Was there a PIO? Easily Induced?	No No	No No	No; very bad undesirable motions. Yes
COMMENTS			
Good Characteristics	Fine tracking was okay with low gain, low amplitude inputs.	Extensive compensation warrants improvement.	None.
Bad Characteristics	Seems to have a tendency for PIO with high gain (almost PIO rating of 4). Not a good feeling airplane for any task, responds slowly to inputs, slowly achieves maximum pitch rate.	Oscillations about target. Nose-up bobble with reversal. Very sluggish gross acquisition. Overshoot on large acquisition 2 times acquisition distance.	Steady-state response slow. Very sluggish. Need to lead the aircraft to stop where I want. Wind-up tendency on large amplitude inputs.

Notes: 1. An "*" indicates test point plotted in Figure C13.2.
2. N/A - not applicable.

Table C28
SUMMARY 2P, RATE LIMIT OF 20 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2P	Rate Limit: 20 degrees per second		Tracking Task: Discrete
Cooper-Harper Ratings: 5* ‖ 4/6/4/8 ‖ 7/3		PIO Ratings: 4* ‖ 3/4/3/4 ‖ 4/1	
Overall Evaluation	Initial response was described as slow. Steady-state response was responsive. The aircraft was predictable for small acquisitions, but unpredictable for larger acquisitions. Gross acquisition was difficult. Fine tracking was maintained within desired criteria. The airplane tracked well under g. Control harmony was good. Stick forces were medium. Overall compensation required was moderate during gross acquisition and fine tracking. Undesirable motions were seen during gross acquisition and fine tracking, particularly when not under g. The airplane felt as if it were winding up during gross acquisitions and it appeared easy to get out of phase. This was eliminated by releasing the stick or backing out of the loop. Though desired performance was attained, this was considered a Level 2 airplane with objectionable deficiencies due to the problems encountered during gross acquisition.		

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. A "/" separates multiple ratings by the same pilot.
3. An "*" indicates test point plotted in Figure C14.

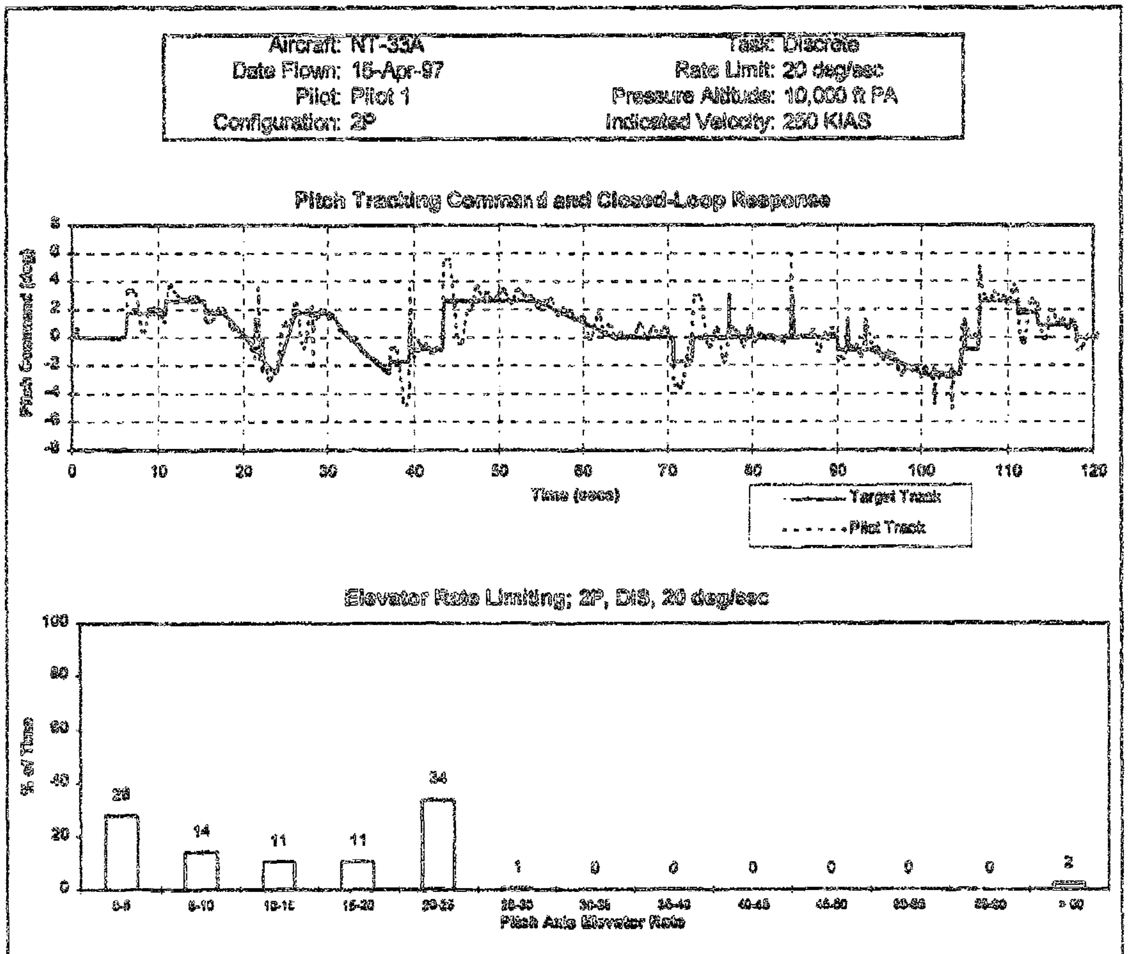

Figure C14 Representative Flight Test Result 2P, Rate Limit of 20 Degrees Per Second, Discrete Task, Pilot 1

Table C29
PILOT COMMENTS FOR 2P, RATE LIMIT OF 20 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2P	Rate Limit: 20 degrees per second		Tracking Task: Discrete
Pilot - Sortie(s)	Pilot 1 - 4*	Pilot 2 - 2/5/7/7	Pilot 3 - 3/8
Cooper-Harper Ratings	5	4/6/4/8	7/3
PIO Ratings	4 (near 3, maybe harsh)	3/4/3/4	4/1
AIRCRAFT			
Initial Response	Slow	Responsive/Fast/Responsive/ Slow	Slow/Slow
Steady-State Response	Responsive	Responsive (all four sorties)	Slow/Slow
Predictable	Yes (except for small lag)	Yes/No (large acquisition)/Yes/No	No/Yes
Gross Acquisition	Difficult (large overshoot and feeling of lag)	Easy/Difficult/Easy (Fine) Difficult (Gross)/Difficult	Difficult/Difficult
Fine Tracking	Desired	Desired (all four sorties)	Desired/Desired
PILOT INTERFACE			
Control Harmony	Good (low-g/Gain)	Good/Poor to good/Good/Poor	Good/Poor
Stick Forces	Medium +	Medium (all four sorties)	Medium/Medium (high side)
Compensation	Minimal (Fine) Moderate + (Gross Acquisition)	Moderate/Moderate/Minimal to moderate/ Moderate to considerable	Moderate/Moderate
Workload	Minimal (Fine) Moderate + (Gross Acquisition)	Tolerable/Tolerable/Minimal/ Tolerable	Tolerable/Tolerable
Was there a PIO? Easily induced?	No No	No/No/No/Yes No/No/No/Yes (large consecutive acquisition)	Yes/No No (lots of oscillations)/No
COMMENTS			
Good Characteristics	Not a bad airplane. Steady-state response was good for task.	None/None/Little overshoot for small acquisitions. Unloads well, negative g acquisitions good. Tracks well under g/Reverses well	None/Good fine tracking overall. No undesirable oscillations.
Bad Characteristics	Heavy stick led to large overshoot in initial capture. I felt a lag. Very close to PIO. I was on the ragged edge of PIO at my gain.	Mild oscillation when not under g, loaded tracking less oscillation about target except with rolling reversal, task performance lost due to small oscillation/One-to-two overshoots during small acquisition, four overshoots in large acquisition/Pitch bobble for low-g track. Large overshoot for large acquisition. Pitch bobble with consecutive gross acquisitions/Poor large acquisition and out of phase for large acquisitions, slow to respond to negative-g acquisitions.	Very slow response - big overshoots, lot of concentration to avoid overshooting the target, felt the aircraft winding up during big pulls; I was able to stop that oscillations by releasing the stick/Pitch steady-state response slow and high stick forces. Gross acquisition difficult and not precise. Plane winds-up with gross acquisition. Bobble under light g, tough to stop on gross acquisition (mildly unpleasant deficiency).

Notes: 1. A "/" separates multiple ratings by the same pilot.
2. An "*" indicates test point plotted in Figure C14.

Table C30
SUMMARY 2P, RATE LIMIT OF 30 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2P	Rate Limit: 30 degrees per second		Tracking Task: Discrete
Cooper-Harper Ratings: 5* ‖ - ‖ 6		PIO Ratings: 3* ‖ - ‖ 3	
Overall Evaluation	Initial aircraft response was slow. Steady-state response was slow to responsive with some lack of predictability. Gross acquisition was assessed by all pilots as difficult due to slow response. Fine tracking adequate criteria was met. Stick forces were medium. Compensation was moderate with a tolerable pilot workload. No indication of a PIO was noted. Overall, the aircraft was slow to respond, but bobbled about the target. A small undesired oscillation was induced about the target during fine tracking. The aircraft was rated as Level 2 due to adequate criteria met and the requirement for considerable pilot compensation.		

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C15.
3. A "-" indicates no rating was given.

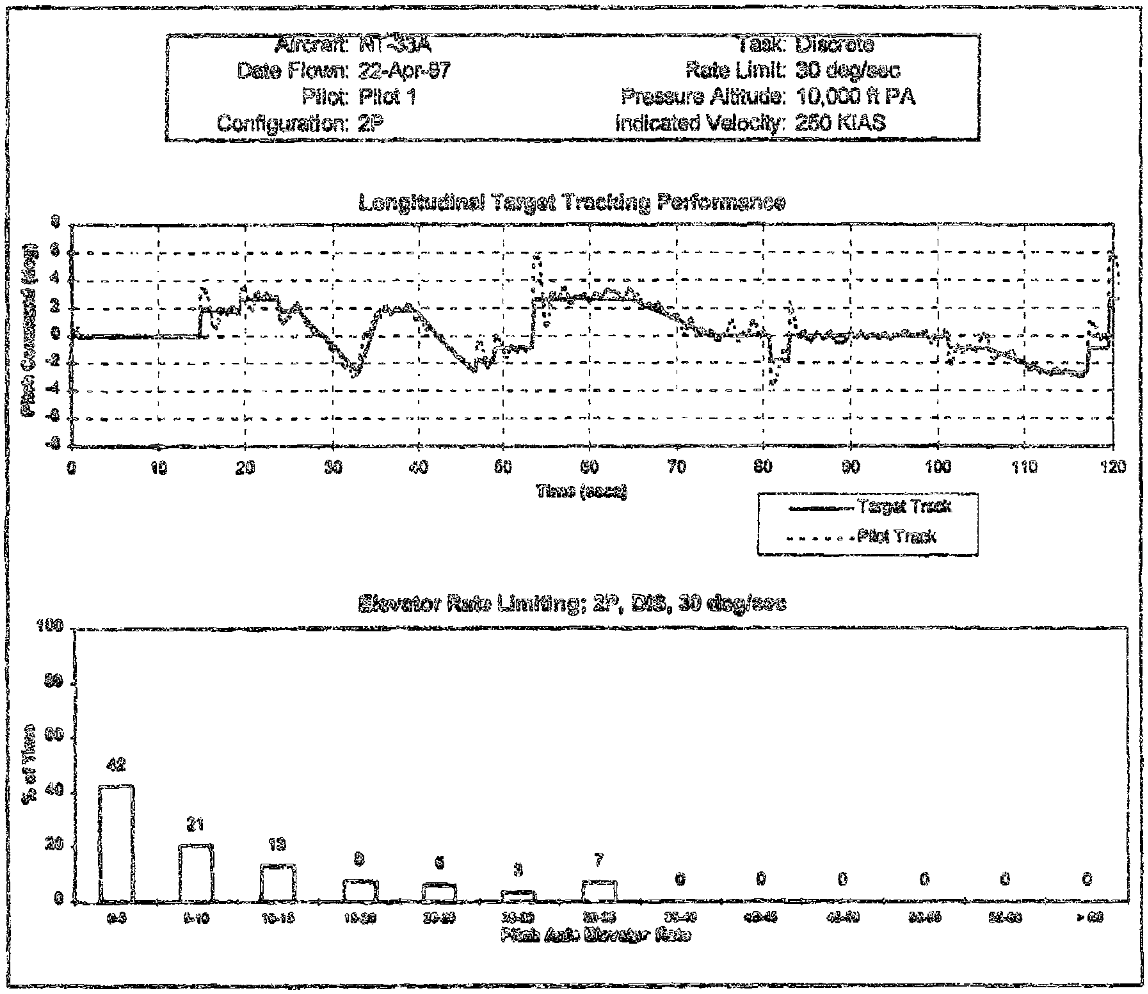

Figure C15 Representative Flight Test Result 2P, Rate Limit of 30 Degrees Per Second, Discrete Task, Pilot 1

Table C31
PILOT COMMENTS FOR 2P, RATE LIMIT OF 30 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2P	Rate Limit: 30 degrees per second		Tracking Task: Discrete
Pilot - Sortie(s)	Pilot 1 - 9*	Pilot 2 - Not Flown	Pilot 3 - 8
Cooper-Harper Ratings	5	Not Flown	6
PIO Ratings	3	Not Flown	3
AIRCRAFT			
Initial Response	Slow	N/A	Slow
Steady-State Response	Responsive (adequate for test)	N/A	Slow
Predictable	Yes (slightly slow)	N/A	No
Gross Acquisition	Easy (adequate) Difficult (desired)	N/A	Difficult
Fine Tracking	Desired	N/A	Adequate
PILOT INTERFACE			
Control Harmony	Good	N/A	Good to poor
Stick Forces	Medium	N/A	High
Compensation	Minimal (Fine) Moderate (Gross)	N/A	Moderate to considerable
Workload	Minimal (Fine) Tolerable (Gross)	N/A	Tolerable to intolerable
Was there a PIO? Easily Induced?	No No	N/A	No No
COMMENTS			
Good Characteristics	N/A	N/A	None.
Bad Characteristics	Slow response led to small overshoots degrading performance. Small residual oscillation.	N/A	Slow initial and steady-state response, undesirable oscillations (two to three) that damp out lowering the gains or freezing the stick, not a comfortable configuration to fly.

Notes: 1. An "*" indicates test point plotted in Figure C15.
2. N/A - not applicable.

Table C32
SUMMARY 2P, RATE LIMIT OF 40 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2P	Rate Limit: 40 degrees per second	Tracking Task: Discrete
Cooper-Harper Ratings: 3 ‖ 6 ‖ 5*/5	PIO Ratings: 2 ‖ 4 ‖ 3*/3	
Overall Evaluation	Initial response was responsive. Steady-state response was slow. The aircraft was predictable during small acquisitions, but lacked predictability during larger acquisitions. Desired performance was attained during fine tracking, tracking with some bounded oscillations. Control harmony was rated as good. Stick forces were medium to high. Compensation required was moderated to considerable. Workload was assessed as tolerable. No PIO was noted, though the aircraft indicated it could diverge during gross acquisition. Required a lot of lead during gross acquisition to stop where desired, then overshooting two to three times. This aircraft was considered a Level 2 aircraft due to the objectionable gross acquisition characteristics and the oscillations about the target during fine tracking.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. A "/" separates multiple ratings by the same pilot.
3. An "*" indicates test point plotted in Figure C16.

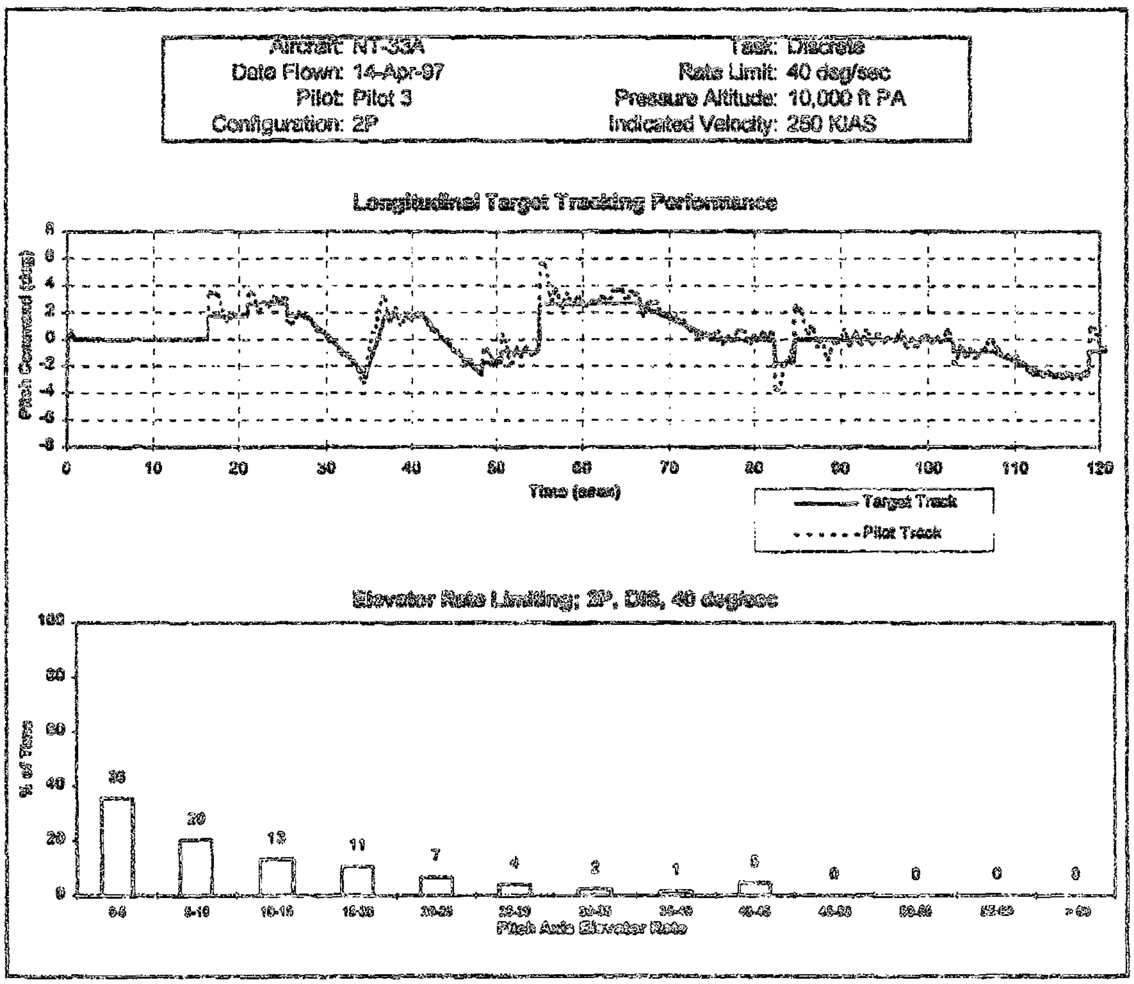

Figure C16 Representative Flight Test Result 2P, Rate Limit of 40 Degrees Per Second, Discrete Task, Pilot 3

Table C33
PILOT COMMENTS FOR 2P, RATE LIMIT OF 40 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2P	Rate Limit: 40 degrees per second		Tracking Task: Discrete
Pilot - Sortie(s)	Pilot 1 - 1	Pilot 2 - 5	Pilot 3 - 3*/6
Cooper-Harper Ratings	3 (tough decision; close to 2)	6	5/5
PIO Ratings	2	4	3/3
AIRCRAFT			
Initial Response	Responsive	Slow	Slow/Responsive
Steady-State Response	Responsive	Slow	Slow/Slow
Predictable	Yes	No	Yes (marginal)/No
Gross Acquisition	Easy	Difficult	Easy/Difficult
Fine Tracking	Desired ("Outstanding")	Desired	Adequate/Desired
PILOT INTERFACE			
Control Harmony	Good	Poor to good	Good/Good
Stick Forces	Medium (solid feel)	Medium to high	Medium/High
Compensation	Minimal	Considerable	Moderate/Moderate
Workload	Minimal	Tolerable	Tolerable/Tolerable
Was there a PIO? Easily Induced?	No No	No No	No/No No/No
COMMENTS			
Good Characteristics	Very good feeling airplane, excellent gross acquisition during fine tracking, the response was slightly slower than previous (2D/Discrete/20).	Stable in high-g banked turn, tracks within desired criteria.	None/None
Bad Characteristics	Slightly objectionable when working around F_s gradient break point.	Two-to-three overshoots during gross acquisition, mild oscillations about the target during fine tracking, small overshoot, oscillation about the target, three overshoots with small acquisition, large acquisition leads to large overshoot, on the edge of wanting to diverge, wants to diverge with large input, poor predictability.	Sluggish during fine tracking, spoiled by annoying bounded oscillations, slow response./Steady-state response excessively slow, it caused a lot of pilot compensation (lead required) to prevent big overshoots.

Notes: 1. A "/" separates multiple ratings by the same pilot.
2. An "*" indicates test point plotted in Figure C16.
3. F_s - Stick force.

Table C34

SUMMARY 2P, RATE LIMIT OF 50 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2P	Rate Limit: 50 degrees per second	Tracking Task: Discrete
Cooper-Harper Ratings: 4* ‖ 5/4 ‖ 3	PIO Ratings: 2* ‖ 3/3 ‖ 2	
Overall Evaluation	Initial and steady-state response were responsive to slow. The aircraft was predictable with easy gross acquisition and desired tracking performance attained. Control harmony was good with medium stick forces. Compensation required was moderate with tolerable workload. No indication of a PIO was seen. The aircraft tracked well under g with some bobbling about the target. Large acquisitions resulted in some large overshoots during initial acquisition. There was some sluggishness during steady-state tracking with slow response to capture commands. The aircraft was considered a Level 2 airplane with minor annoying deficiencies, while still able to attain desired performance.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3. 3. An "*" indicates test point plotted in Figure C17.
2. A "/" separates multiple ratings by the same.

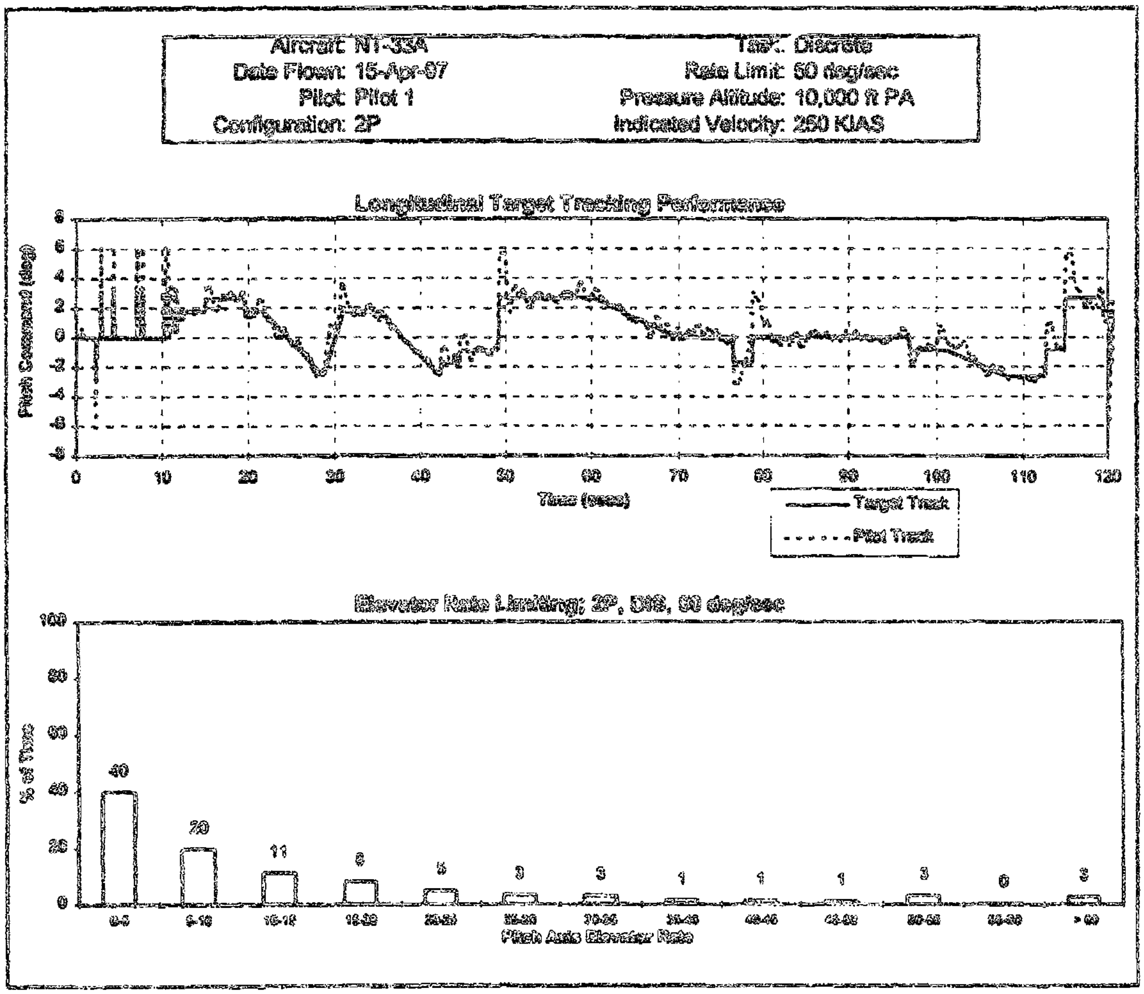

Figure C17 Representative Flight Test Result 2P, Rate Limit of 50 Degrees Per Second, Discrete Task, Pilot 1

Table C35
PILOT COMMENTS FOR 2P, RATE LIMIT OF 50 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2P	Rate Limit: 50 degrees per second		Tracking Task: Discrete
Pilot - Sortie(s)	Pilot 1 - 4*	Pilot 2 - 2/5	Pilot 3 - 3
Cooper-Harper Ratings	4	5/4	3
PIO Ratings	2	3/3	2
AIRCRAFT			
Initial Response	Responsive	Responsive/Responsive	Slow
Steady-State Response	Responsive	Responsive/Slow	Slow
Predictable	Yes	Yes/Yes	Yes
Gross Acquisition	Easy (couple of overshoots, not bad)	Easy/Easy	Easy
Fine Tracking	Desired	Adequate/Desired	Desired
PILOT INTERFACE			
Control Harmony	Good (tended to drive inadvertent roll input)	Good/Good	Good
Stick Forces	Low + (at higher g)	Medium/Medium	Medium (heavy pitch force)
Compensation	Minimal	Moderate/Minimal to Moderate	Moderate
Workload	Minimal (Fine) Tolerable (Gross)	Tolerable/Tolerable	Tolerable
Was there a PIO? Easily Induced?	No No	No/No No/No	No No
COMMENTS			
Good Characteristics	Excellent fine track	None/One overshoot for a large acquisition, predictable, tracks well under g, no oscillation about target.	Good overall, tracking characteristics, configuration can be employed on a wide variety of airplanes (fighter, transport, ...).
Bad Characteristics	Couple of overshoots	Bobbling about target, difficult to stabilize, three-to-four overshoots on gross acquisition, large jumps lead to large overshoots, small oscillations under loaded tracking, pilot compensation to eliminate bobbles, lost performance/Sluggish steady response, slow to respond to capture.	Little sluggish in pitch response, two overshoots during gross acquisition but performance is not compromised.

Notes: 1. A "/" separates multiple ratings by the same pilot.
2. An "*" indicates test point plotted in Figure C17.

Table C36

SUMMARY 2P, RATE LIMIT OF 157 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2P			Rate Limit: 157 degrees per second		Tracking Task: Discrete	
Cooper-Harper Ratings: 4*	-	4	PIO Ratings: 2*	-	2	
Overall Evaluation	Initial and steady-state response were described as slow to responsive. The aircraft was predictable and fine tracking performance met desired criteria with minimal to moderate compensation required. Gross acquisition was described as easy. Workload was minimal to tolerable and no tendency to PIO was noted. The aircraft handling was described as excellent, very responsive and felt great. The second pilot commented that the aircraft was a bit sluggish, much like a transport, with some minor annoying oscillations under g. Overall, this configuration was rated as Level 2 for minor but annoying deficiencies.					

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C18.
3. A "-" indicates no rating was given.

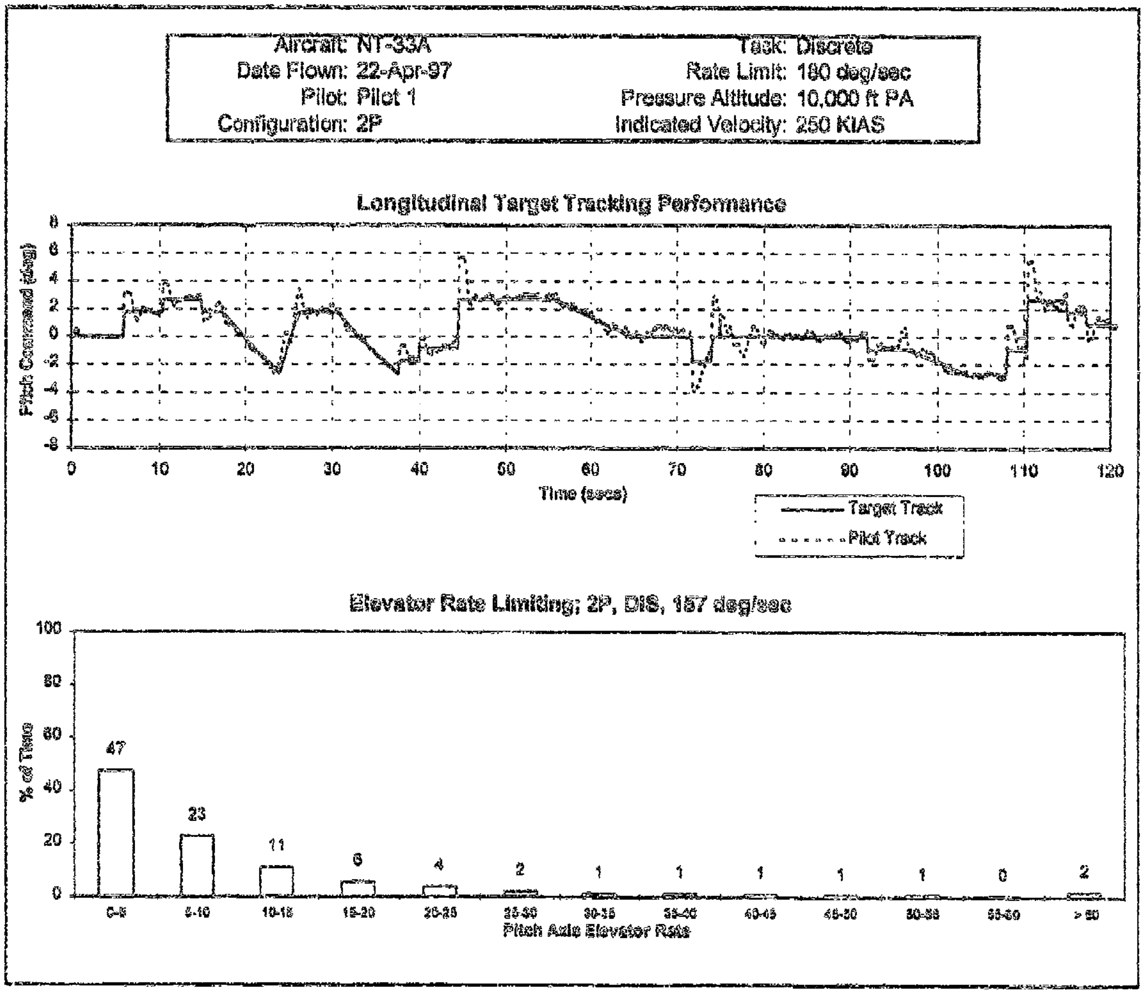

Figure C18 Representative Flight Test Result 2P, Rate Limit of 157 Degrees Per Second, Discrete Task, Pilot 1

Table C37
PILOT COMMENTS FOR 2P, RATE LIMIT OF 157 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2P	Rate Limit: 157 degrees per second		Tracking Task: Discrete
Pilot - Sortie(s)	Pilot 1 - 9*	Pilot 2 - Not Flown	Pilot 3 - 8
Cooper-Harper Ratings	4	Not Flown	4
PIO Ratings	2	Not Flown	2
AIRCRAFT			
Initial Response	Responsive	N/A	Slow
Steady-State Response	Responsive	N/A	Slow
Predictable	Yes	N/A	Yes
Gross Acquisition	Easy	N/A	Easy
Fine Tracking	Desired	N/A	Desired
PILOT INTERFACE			
Control Harmony	Good	N/A	Good
Stick Forces	Low (at low-g) Medium (at increased g)	N/A	Medium to high
Compensation	Minimal	N/A	Moderate
Workload	Minimal	N/A	Tolerable
Was there a PIO? Easily Induced?	No No	N/A	No No
COMMENTS			
Good Characteristics	Excellent aircraft, very responsive, felt great.	N/A	None
Bad Characteristics	Control harmony gradient was noticeable at higher g (this was the only reason for Cooper-Harper rating of 4), the stick force gradient caused some minor unwanted pitch oscillations.	N/A	Slow and sluggish transport type aircraft with 2 to 3 oscillations under g (minor but annoying deficiency).

Notes: 1. An "*" indicates test point plotted in Figure C18.
2. N/A - not applicable.

Table C38
SUMMARY 2P, RATE LIMIT OF 10 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2P	Rate Limit: 10 degrees per second		Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 8 | 9 | 8*		PIO Ratings: 4 | 4 | 4*	
Overall Evaluation	Initial and steady-state response in this aircraft were described by all pilots as slow. The aircraft lacked predictability and was very difficult to control. Gross acquisition was difficult requiring intense workload to remain in phase. The pilot had to back out of the loop to reduce gains and allow the aircraft to dampen out. Fine tracking could not be accomplished. Stick harmony was poor, with medium to high control forces. Compensation was considerable and workload intolerable. A PIO was easily induced early in the task. Aircraft control could only be maintained by backing out of the loop. No divergent oscillations were seen. This aircraft was rated Level 3 requiring improvement for major deficiencies.		

Notes: 1. The order of ratings is Pilot 1 | Pilot 2 | Pilot 3.
2. An "*" indicates test point plotted in Figure C19.

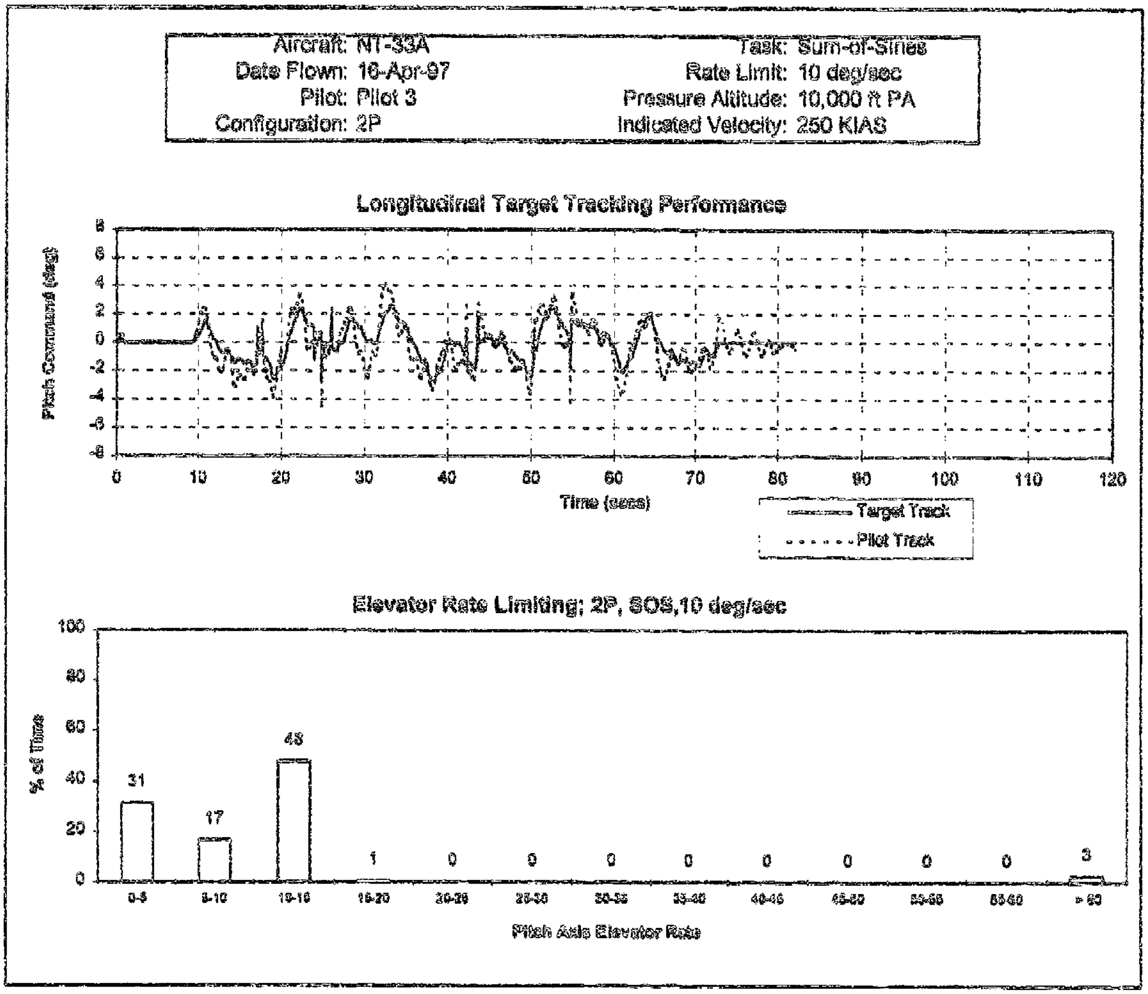

Figure C19 Representative Flight Test Result 2P, Rate Limit of 10 Degrees Per Second, Sum-of-Sines Task, Pilot 3

Table C39
PILOT COMMENTS FOR 2P, RATE LIMIT OF 10 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2P	Rate Limit: 10 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 4	Pilot 2 - 7	Pilot 3 - 6*
Cooper-Harper Ratings	8	9 (control in question)	8
PIO Ratings	4 (increased gain to maintain control)	4	4
AIRCRAFT			
Initial Response	Very slow	Slow	Slow
Steady-State Response	Slow	Slow	Slow
Predictable	No	No	No
Gross Acquisition	Difficult	Difficult	Difficult
Fine Tracking	Adequate (using very low gain)	Could not do	N/A
PILOT INTERFACE			
Control Harmony	N/A	N/A	N/A
Stick Forces	High	Medium	Medium
Compensation	Considerable	Considerable	Considerable
Workload	Intolerable	Intolerable	Tolerable +
Was there a PIO? Easily Induced?	Yes Yes	Yes Yes (entered early in task)	Yes Yes
COMMENTS			
Good Characteristics	None	None	None
Bad Characteristics	Extremely heavy stick. Terrible feeling aircraft. Control harmony problems drive lots of inadvertent roll inputs. Flyable but workload is so high that controllability is always in question. Requires stop to stop pitch inputs.	Extreme lag in initial response 180 degrees out of phase PIO. Had to reduce gain, back out of loop to dampen out. Not divergent, dampened with release of stick.	Steady-state response was very slow and unpredictable. A lot of lead required to contain the amplitude of the undesirable oscillations. Sluggish.

Notes: 1. An "*" indicates test point plotted in Figure C19.
2. N/A - not applicable.

Table C40
SUMMARY 2P, RATE LIMIT OF 20 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2P	Rate Limit: 20 degrees per second	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 5* ‖ 8/5/8 ‖ 6	PIO Ratings: 4* ‖ 5/4/5 ‖ 4	
Overall Evaluation	Initial aircraft response was slow to responsive. Steady-state response was slow to responsive with some lack of predictability. Gross acquisition was assessed by all pilots as difficult due to large overshoots. The aircraft felt as if it were getting out of phase. Fine tracking met adequate criteria, with performance increasing with decreasing of gains. Moderate to considerable compensation was required to achieve adequate criteria with a tolerable workload. The summation of the pilot comments indicates there was some easily induced PIO during gross acquisition. The PIO appeared bounded making desired tracking impossible. The aircraft was rated by one pilot as Level 3 and as Level 2 by the other evaluation pilots. Given the noted PIO and difficulty with gross acquisition, the aircraft required improvement for major deficiency and should be considered Level 3.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. A "/" separates multiple ratings by the same pilot.
3. An "*" indicates test point plotted in Figure C20.

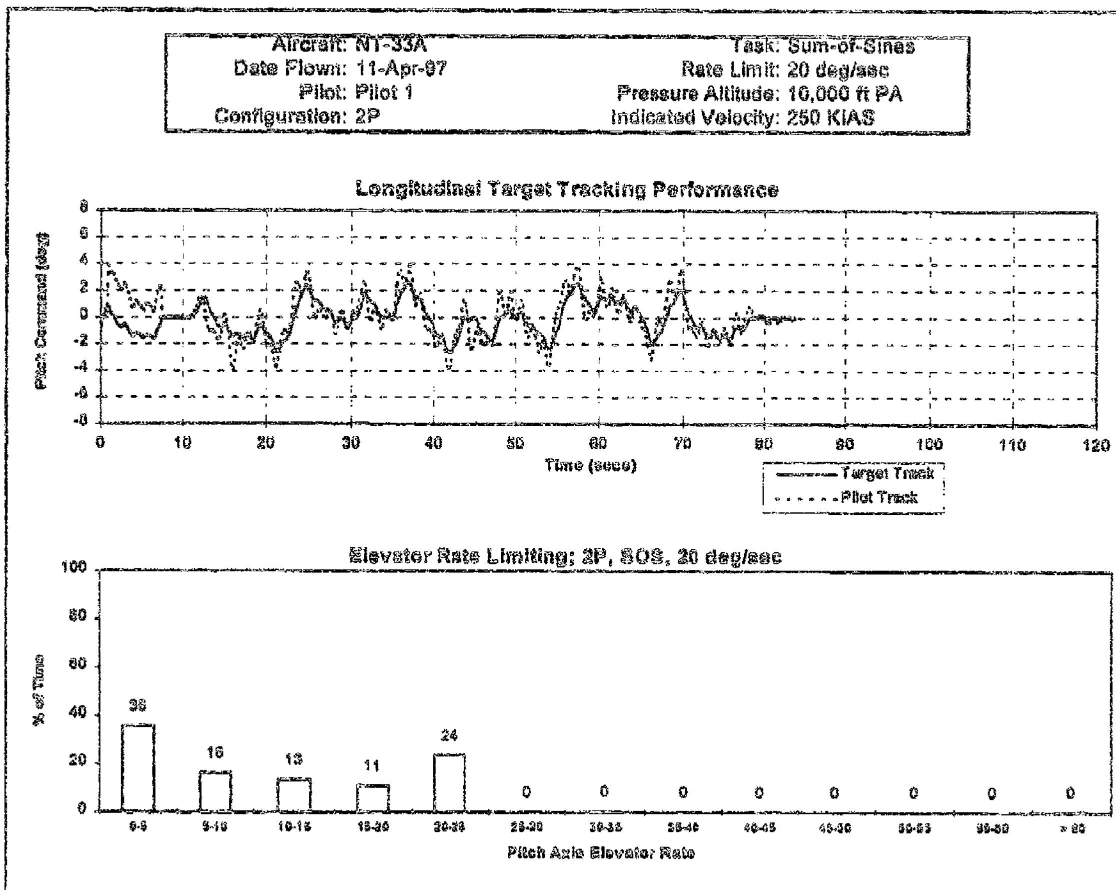

Figure C20 Representative Flight Test Result 2P, Rate Limit of 20 Degrees Per Second, Sum-of-Sines Task, Pilot 1

Table C41
PILOT COMMENTS FOR 2P, RATE LIMIT OF 20 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2P	Rate Limit: 20 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 1*	Pilot 2 - 2/5/7	Pilot 3 - 6
Cooper-Harper Ratings	5	8/5/8	6
PIO Ratings	4	5/4/5	4
AIRCRAFT			
Initial Response	Slow	Fast/Responsive/Responsive	Slow
Steady-State Response	Responsive	Fast/Slow/Responsive	Slow
Predictable	Yes to no	No; difficult with fast onset/ No/No	No
Gross Acquisition	Difficult (4-5 overshoots)	Difficult/Difficult/Difficult (large acquistions)	Difficult
Fine Tracking	Adequate	Bordering on adequate/Other than adequate/Adequate to desired (when open loop)	Adequate
PILOT INTERFACE			
Control Harmony	N/A	Poor to good (too much response)/Poor to good/Poor	N/A
Stick Forces	Low to medium	Medium(3)	High side of medium
Compensation	Moderate (adequate)	Considerable(3)	High side of moderate
Workload	Tolerable	Tolerable(3)	High side of tolerable
Was there a PIO? Easily Induced?	Yes (slight) Yes (for Gross Acquisition)	No/No/No No/No/No	Yes Yes
COMMENTS			
Good Characteristics	Fine. OK.	None/None/Small acquisitions easy to do.	N/A
Bad Characteristics	Small PIO tendency with large amplitude aggressive task. Overly sensitive. Drove overshoots during initial captures.	Large overshoot with large target jump, feels on edge of wanting to diverge with gross acquisition, stopped with opposite stick. Had to abandon task to recover jet. Did not diverge. If task had continued with larger jump, this may have diverged/Small oscillations about target. Poor predictability. Difficult to stabilize. Bouncing back and forth across target, not stabilizing. Tracked this 2 times to try and get feel for the problem. Bobbling about the target. Difficult to stabilize on target. Getting out of phase with tight in-the-loop control. Open loop dampens out.	I was in doubt between 6 and 7. I decided for 6 because flying low gains improved the tracking quality (very objectionable but tolerable deficiencies). Not predictable at all. Pretty good amplitude oscillation. Bounded PIO observed. Good tracking is impossible.

Notes: 1. A "/" separates multiple ratings by the same pilot.
2. An "*" indicates test point plotted in Figure C20.
3. N/A - not applicable.

Table C42
SUMMARY 2P, RATE LIMIT OF 30 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2P	Rate Limit: 30 degrees per second	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 4 ‖ 5* ‖ 6	PIO Ratings: 3 ‖ 3* ‖ 3	
Overall Evaluation	Initial aircraft response was slow. Steady-state response was slow to responsive with some lack of predictability. Gross acquisition was assessed by all pilots as difficult due to slow response. Fine tracking adequate criteria was met. Stick forces were medium. Compensation was moderate with a tolerable pilot workload. No indication of a PIO was noted. Overall, the aircraft was slow to respond, but bobbled about the target. A small undesired oscillation was induced about the target during fine tracking. The aircraft was rated as Level 2 due to adequate criteria met and the requirement for considerable pilot compensation.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C21.

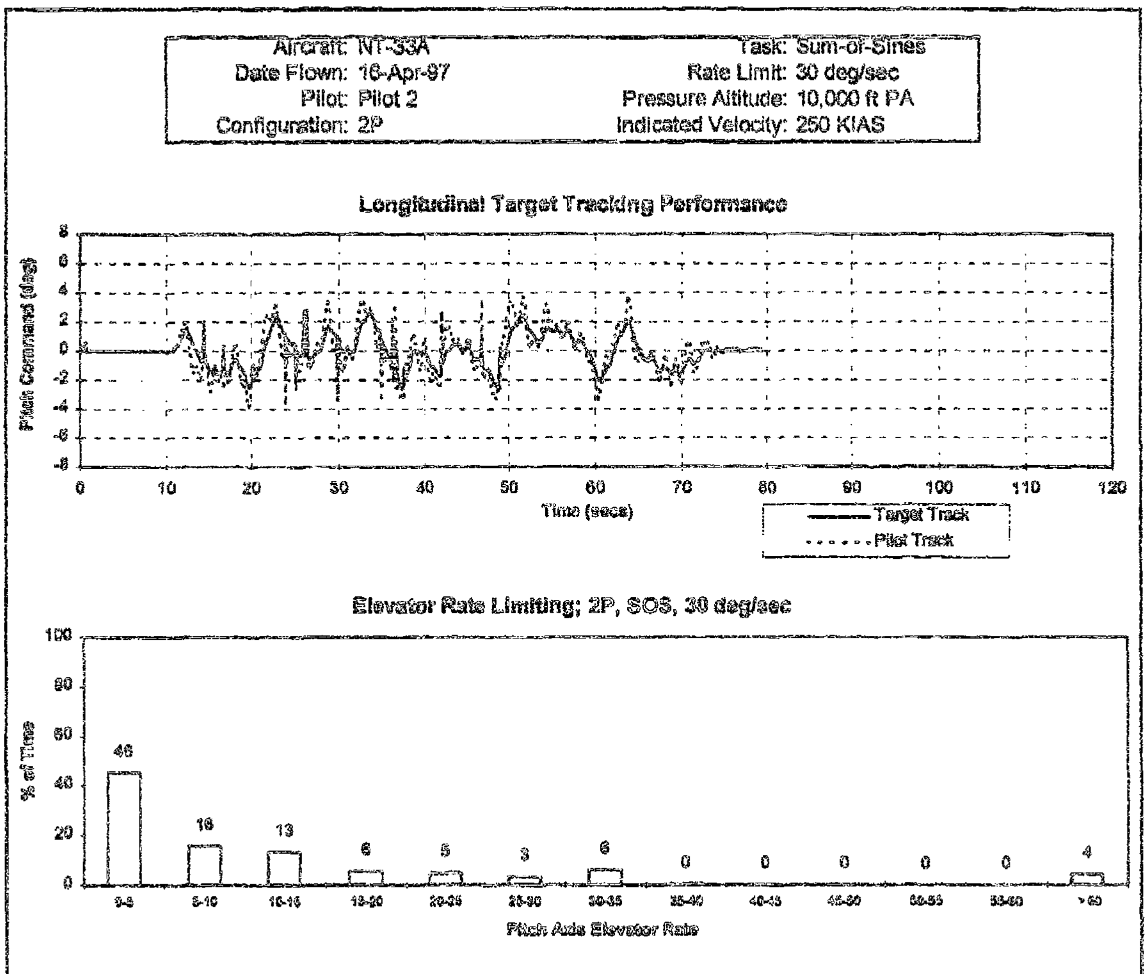

Figure C21 Representative Flight Test Result 2P, Rate Limit of 30 Degrees Per Second, Sum-of-Sines Task, Pilot 2

Table C43

PILOT COMMENTS FOR 2P, RATE LIMIT OF 30 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2P	Rate Limit: 30 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 9	Pilot 2 - 7*	Pilot 3 - 8
Cooper-Harper Ratings	4	5	6
PIO Ratings	3	3	3
AIRCRAFT			
Initial Response	Slow	Slow	Slow
Steady-State Response	Responsive (for the task)	Responsive	Slow
Predictable	Yes	Yes (small unpredictability)	No
Gross Acquisition	Difficult (slightly)	Easy to difficult	Difficult
Fine Tracking	Desired	Adequate	Adequate
PILOT INTERFACE			
Control Harmony	N/A	N/A	N/A
Stick Forces	Medium	Medium	Medium
Compensation	Minimal (for Fine Tracking) Moderate (for Gross Acquisition)	Minimal to moderate	Moderate to considerable
Workload	Minimal (for Fine Tracking) Tolerable (for Gross Acquisition)	Tolerable	Tolerable to intolerable
Was there a PIO? Easily Induced?	No No	No No	No No
COMMENTS			
Good Characteristics	Nice, fine tracking.	Steady-state response OK.	None
Bad Characteristics	Sluggish initially, decrease in predictability due to slow response.	Some deficiency with gross acquisition. Slow to respond. Slightly sluggish. Slow to initial response. Little bobble about target.	Very slow initial and steady-state response, for this reason gross acquisition required extensive pilot compensation (input shaping), undesired oscillation easily induced.

Notes: 1. An "*" indicates test point plotted in Figure C21.

2. N/A - not applicable.

Table C44
SUMMARY 2P, RATE LIMIT OF 40 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2P	Rate Limit: 40 degrees per second	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 5 ‖ 7/4/5 ‖ 5*	PIO Ratings: 4 ‖ 4/3/3 ‖ 3*	
Overall Evaluation	Initial response was assessed as slow to responsive. Overall steady-state response was responsive. The aircraft lacked complete predictability due to some nose lag following an input. Gross acquisition was difficult, with some overshoots during large acquisitions. Fine tracking attained adequate performance criteria. Compensation required was moderate for a tolerable workload. No PIO was seen, though one pilot felt a tendency to get into one if aggressive stick inputs were made. There was difficulty stabilizing on the target due to mild oscillation. These could be eliminated with some pilot compensation. Overall rating for this aircraft was Level 2 with adequate performance attained and considerable pilot compensation required.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3. 3. An "*" indicates test point plotted in Figure C22.
2. A "/" seperates multiple ratings by the same pilot.

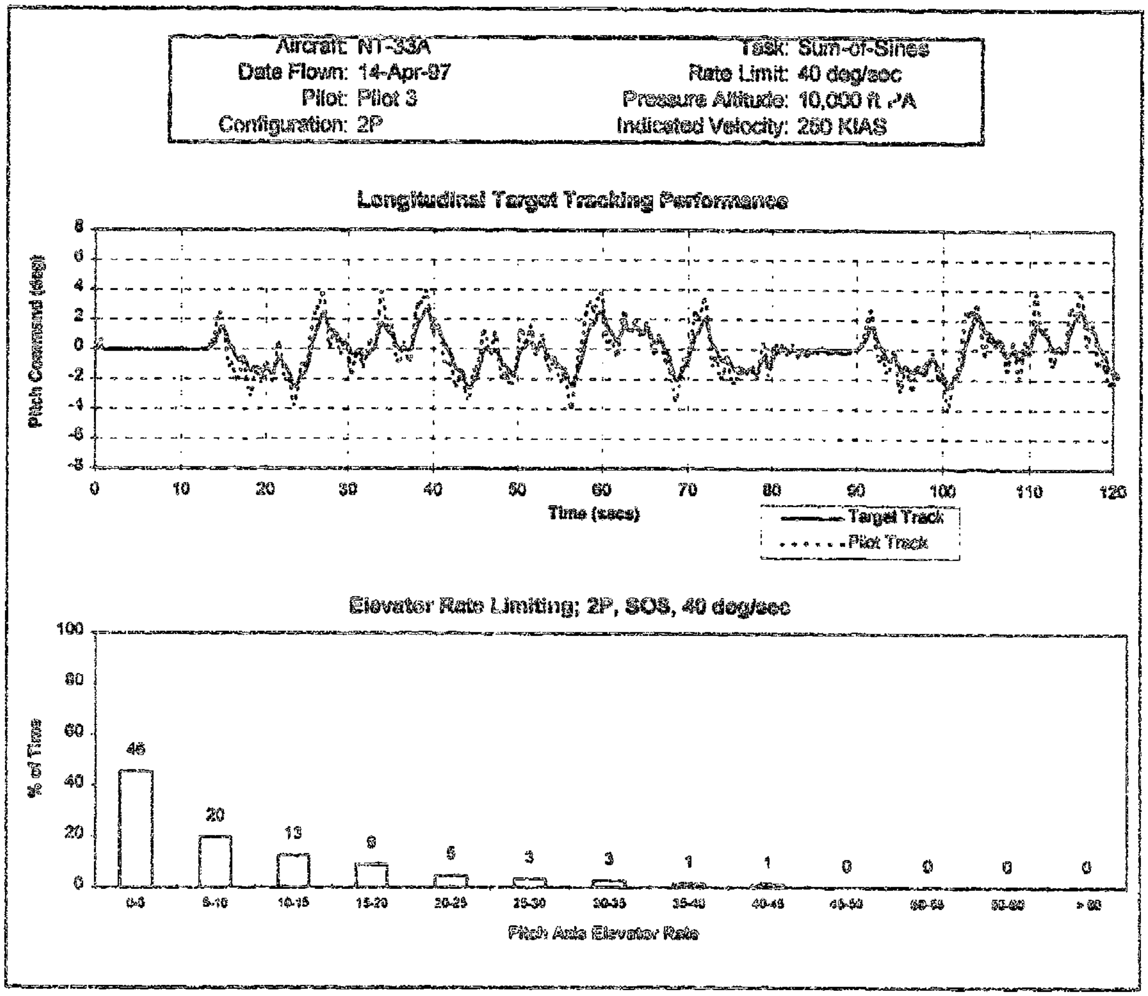

Figure C22 Representative Flight Test Result 2P, Rate Limit of 40 Degrees Per Second, Sum-of-Sines Task, Pilot 3

Table C45

PILOT COMMENTS FOR 2P, RATE LIMIT OF 40 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2P	Rate Limit: 40 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 4	Pilot 2 - 2/5/7	Pilot 3 - 3*
Cooper-Harper Ratings	5 (close to 6)	7 (could not get adequate, controllability not in question)/4/5	5
PIO Ratings	4	4/3/3	3
AIRCRAFT			
Initial Response	Slow	Responsive (3)	Slow
Steady-State Response	Responsive	Responsive (3)	Slow
Predictable	Yes (generally due to delay in pitch)	No/Yes/Yes	No
Gross Acquisition	Difficult	Easy/Easy to difficult/ Easy (some overshoot with large acquisition)	Difficult
Fine Tracking	Adequate	Difficult (not adequate due to task)/Adequate/Adequate to desired	Adequate
PILOT INTERFACE			
Control Harmony	N/A	Good (3)	N/A
Stick Forces	Medium (stiff stick)	Medium (3)	Medium
Compensation	Moderate	Moderate/Moderate/ Moderate (for large acquisitions)	Moderate
Workload	Tolerable	Tolerable/Tolerable/ Minimal to tolerable	Tolerable
Was there a PIO? Easily Induced?	Yes (tendency) No	No/No/No No/No/No	No No
COMMENTS			
Good Characteristics	Not bad feeling. Adequate achieved.	None/None/None	None
Bad Characteristics	Heavy stick. Nose lags desired input. Heavy stick. Aggressive inputs lead to PIO.	Difficult to stabilize on target. Oscillations about target. Mild oscillations, not divergent. Attempted to reduce gains to zero in on target. Small bobbling about the target. Eliminate w/pilot compensation. Some undesirable motions with overshoots for gross acquisitions. Caused degrees rotation in performance.	Have to say low gain to track. Two to three oscillations above the target. The aircraft appears to lag pilots inputs. Slow overall response.

Notes: 1. A "/" separates multiple ratings by the same pilot.
2. An "*" indicates test point plotted in Figure C22.
3. N/A - not applicable.

Table C46

SUMMARY 2P, RATE LIMIT OF 50 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2P	Rate Limit: 50 degrees per second	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 5 ‖ 4 ‖ 5*	PIO Ratings: 3 ‖ 2 ‖ 3*	
Overall Evaluation	Initial and steady-state response were slow to responsive. The aircraft was noted as predictable by 2/3 evaluation pilots. Gross acquisition was judged as easy to difficult, with one pilot attaining desired fine tracking criteria. Compensation required was moderate during gross acquisition, and slightly reduced during fine tracking. No indication of a PIO was noted. The aircraft stabilized on the target and tracked without oscillations seen previously. The aircraft was described as being springy, resulting in some overshoots of the target during gross acquisition. Overall assessment of the aircraft was Level 2 due to the problems associated with both fine tracking and gross acquisition.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C23.

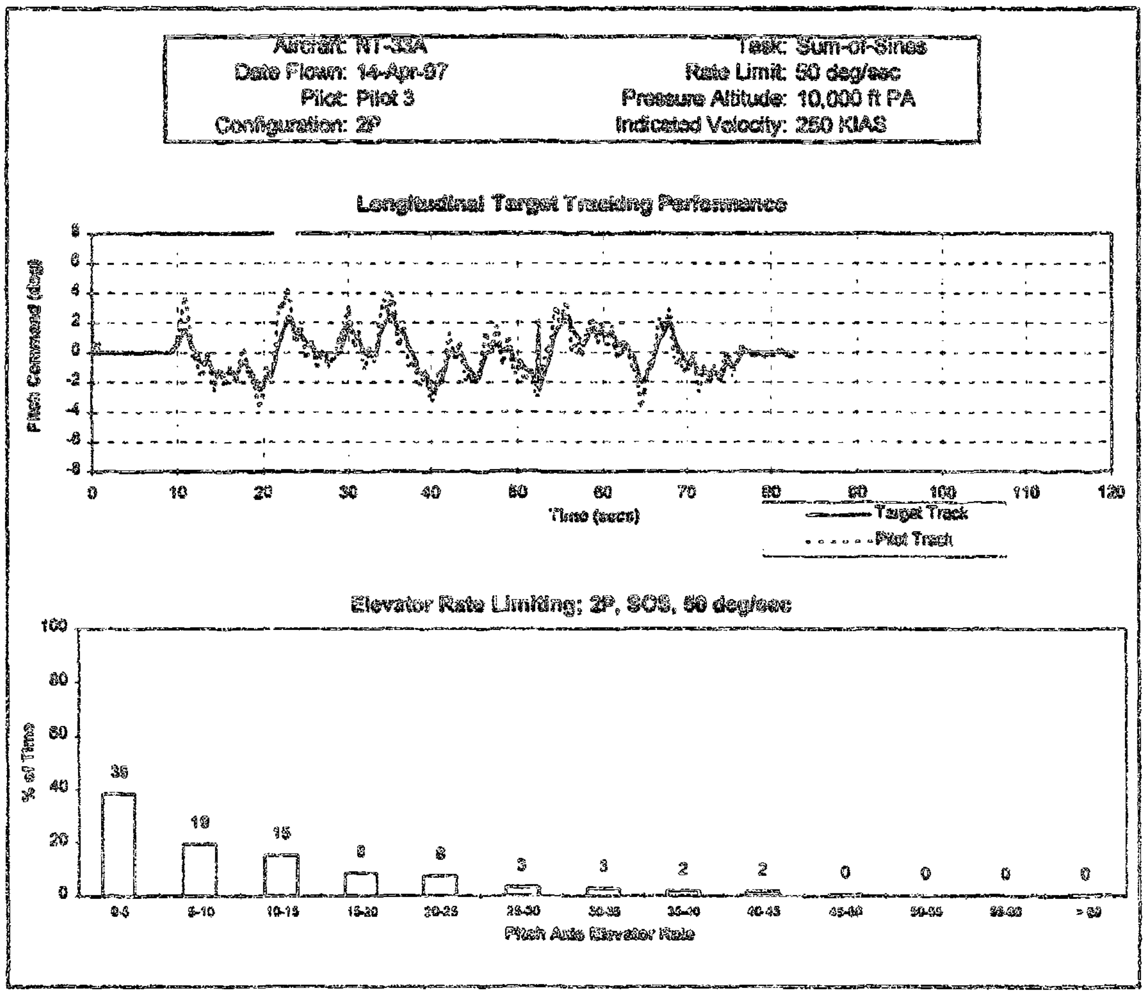

Figure C23 Representative Flight Test Result 2P, Rate Limit of 50 Degrees Per Second, Sum-of-Sines Task, Pilot 3

Table C47
PILOT COMMENTS FOR 2P, RATE LIMIT OF 50 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2P	Rate Limit: 50 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 4	Pilot 2 - 2	Pilot 3 - 3*
Cooper-Harper Ratings	5	4	5
PIO Ratings	3	2	3
AIRCRAFT			
Initial Response	Responsive	Responsive	Slow
Steady-State Response	Responsive	Responsive	Slow
Predictable	Yes	Yes	No
Gross Acquisition	Difficult	Easy	Difficult
Fine Tracking	Desired	Adequate	Adequate
PILOT INTERFACE			
Control Harmony	Good	Good	N/A
Stick Forces	Medium +	Medium	Medium
Compensation	Minimal (Fine) Moderate (Gross)	Moderate	Moderate
Workload	Minimal Moderate (Gross)	Tolerable	Tolerable (high side)
Was there a PIO? Easily Induced?	No No	No No	No No
COMMENTS			
Good Characteristics	Good fine track	Stabilized and tracked target without mild oscillations seen previously	None
Bad Characteristics	Gross acquisition - adequate only. "Springy" feel led to constant small oscillations and large overshoots during initial capture.	Still compensating a bit for airplane in gross acquisition and fine tracking. Not able to get desired performance.	Slow aircraft response. Tends to overshoot. Got desired by workload too high to give a CH 4.

Notes: 1. An "*" indicates test point plotted in Figure C23.
2. N/A - not applicable.

Table C48
SUMMARY 2P, RATE LIMIT OF 157 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2P	Rate Limit: 157 degrees per second	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 5* ‖ - ‖ 5	PIO Ratings: 3* ‖ - ‖ 3	
Overall Evaluation	Initial response was described as slow, with steady-state response slow to responsive. The aircraft was somewhat predictable, decreasing during the gross acquisition phase, making gross acquisition difficult. The fine tracking met adequate criteria due to a slow response and some small oscillations about the target. Compensation required was moderate with a tolerable workload. No tendency to PIO was noted during the tracking task, though some undesired oscillations were seen about the target during high gain tracking. Overall, the aircraft was slow and sluggish to respond with a heavy stick feel. The aircraft was rated as Level 2 due to the adequate performance and objectionable oscillations.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3. 3. A "-" indicates no rating was given.
2. An "*" indicates test point plotted in Figure C24.

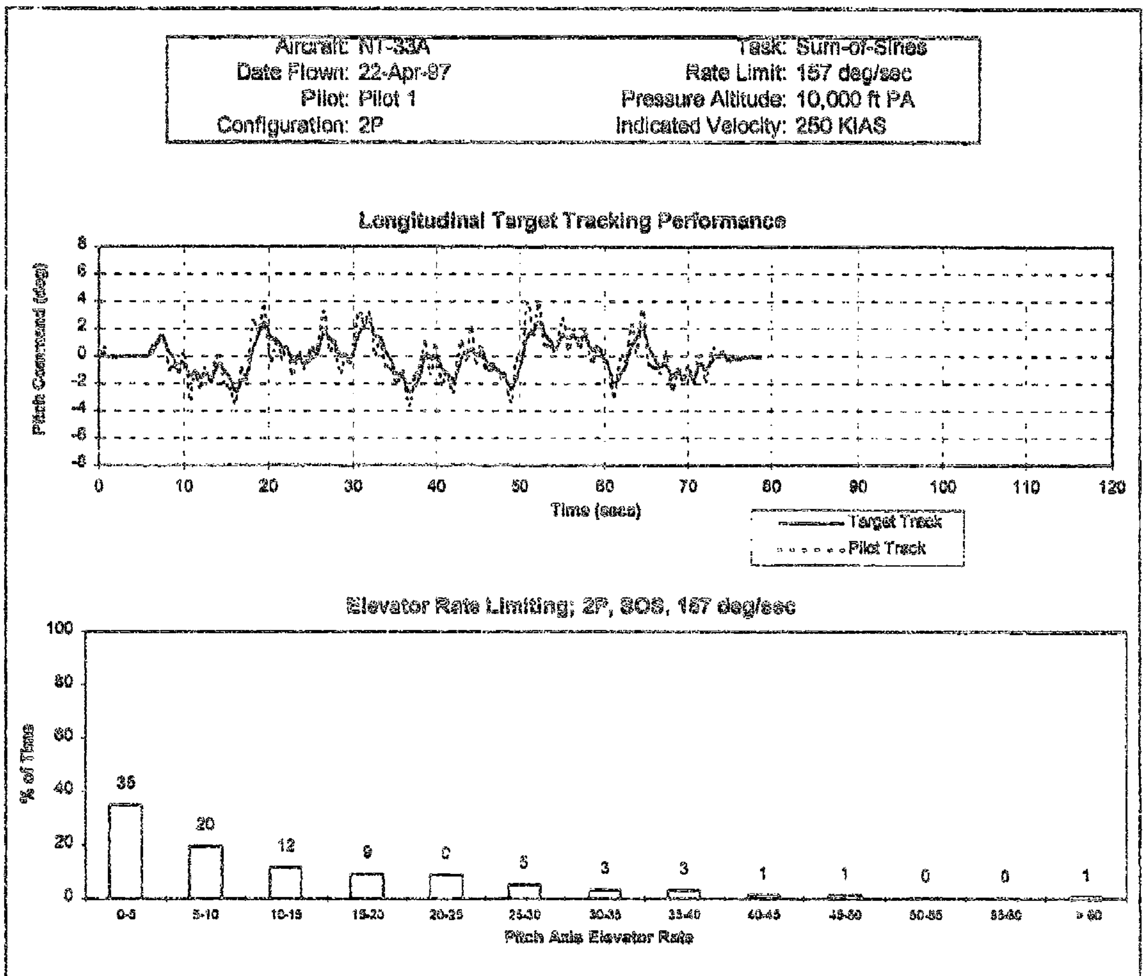

Figure C24 Representative Flight T esult 2P, Rate Limit of 157 Degrees Per Second, Sum-of-Sines Task, Pilot 1

Table C49
PILOT COMMENTS FOR 2P, RATE LIMIT OF 157 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2P	Rate Limit: 157 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 9*	Pilot 2 - Not Flown	Pilot 3 - 8
Cooper-Harper Ratings	5	Not Flown	5
PIO Ratings	3	Not Flown	3
AIRCRAFT			
Initial Response	Slow	N/A	Slow
Steady-State Response	Responsive	N/A	Slow
Predictable	Yes (fine, a little less for Gross Acquisition but okay.)	N/A	No
Gross Acquisition	Difficult (adequate; sluggish pitch response with low damping)	N/A	Difficult (especially at high pilot gains)
Fine Tracking	Adequate	N/A	Adequate
PILOT INTERFACE			
Control Harmony	N/A	N/A	N/A
Stick Forces	Medium	N/A	Medium to high
Compensation	Moderate (throughout)	N/A	Moderate
Workload	Tolerable	N/A	Tolerable
Was there a PIO? Easily Induced?	No No	N/A	No No
COMMENTS			
Good Characteristics	N/A	N/A	None.
Bad Characteristics	A bit slow response with slightly heavy stick. Sluggish, undamped short period.	N/A	Small long period oscillations about the target (2 to 3), very slow and sluggish, undesired oscillations at high pilot gains easily induced.

Notes: 1. An "*" indicates test point plotted in Figure C24.
2. N/A - not applicable.

Table C50

SUMMARY 2DU, RATE LIMIT OF 20 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2DU	Rate Limit: 20 degrees per second	Tracking Task: Discrete
Cooper-Harper Ratings: 10* ‖ 10 ‖ 10	PIO Ratings: 6* ‖ 6 ‖ 5	
Overall Evaluation	The aircraft pitch response was extremely sensitive to pilot gains and overall uncontrollable. Even if the pitch response was responsive to fast, the pilot was able to track the target with moderate compensation and tolerable workload within the adequate performance criteria as long as his inputs were smooth and controlled. On more aggressive or larger corrections the aircraft was over-responsive and unpredictable and the onset of divergent oscillations was unavoidable.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C25.

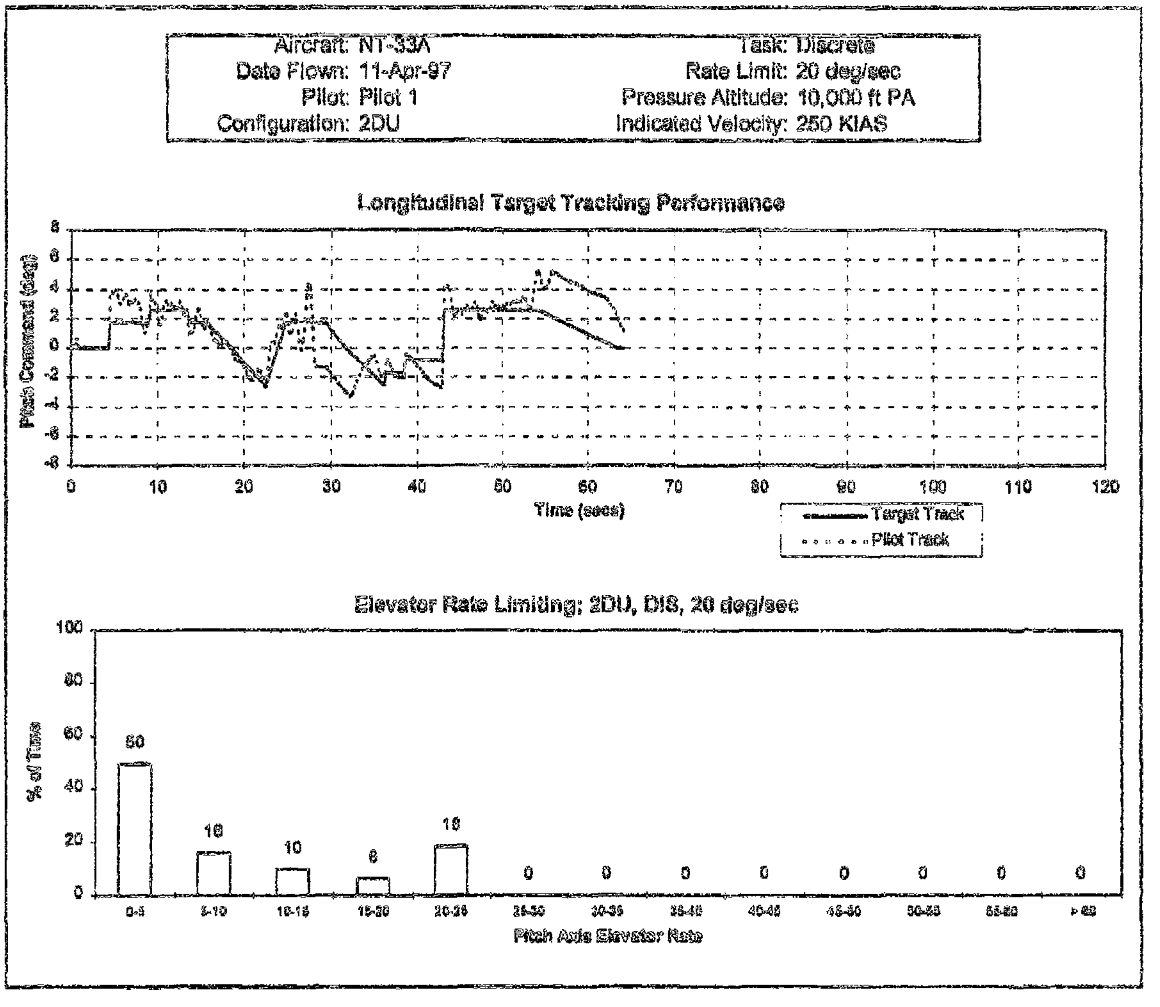

Figure C25 Representative Flight Test Result 2DU, Rate Limit of 20 Degrees Per Second, Discrete Task, Pilot 1

Table C51
PILOT COMMENTS FOR 2DU, RATE LIMIT OF 20 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2DU	Rate Limit: 20 degrees per second		Tracking Task: Discrete
Pilot - Sortie(s)	Pilot 1 - 1*	Pilot 2 - 5	Pilot 3 - 3
Cooper-Harper Ratings	10	10	10
PIO Ratings	6	6	5
AIRCRAFT			
Initial Response	Responsive - Fast	Fast	Responsive
Steady-State Response	Responsive	Fast	Responsive
Predictable	Yes (at low gain/amplitude) No (at high gain)	No	No
Gross Acquisition	Difficult	Difficult	Easy (for small inputs) Difficult (for large steps)
Fine Tracking	Adequate	Adequate (while fine tracking)	Adequate
PILOT INTERFACE			
Control Harmony	Good	Poor	Good
Stick Forces	Low	Medium	Medium
Compensation	Moderate + (at high gain and amplitude)	Moderate +	Moderate
Workload	Tolerable (low gain) Intolerable (at high gain/amplitude)	Intolerable	Tolerable
Was there a PIO? Easily Induced?	Yes Yes	Yes Yes	Yes No
COMMENTS			
Good Characteristics	Not bad at low-g and small amplitude.	Tracked with low gain. Any aggressive input diverged.	None
Bad Characteristics	Over-responsive. Unflyable for large amplitude task. I started getting used to the F_s gradient.	Divergent with initial in the loop. Ugly. Easily induced with gross acquisition.	Continuous bobble over the target. Small, low gain control inputs do not expose the oscillations. Sluggish response.

Notes: 1. An "*" indicates test point plotted in Figure C25.

Table C52

SUMMARY 2DU, RATE LIMIT OF 30 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2DU	Rate Limit: 30 degrees per second	Tracking Task: Discrete
Cooper-Harper Ratings: 9 ‖ - ‖ 10*		PIO Ratings: 5 ‖ - ‖ 5*
Overall Evaluation	The initial pitch response as well as the steady-state response were responsive. The steady-state response was unpredictable so that the gross acquisition of the target was difficult with two to three overshoots. The amplitude and frequency of those oscillations were surprising to the pilot that was forced to raise workload and the level of compensation required to track the target. Notwithstanding the considerable pilot effort the target could not be tracked within the adequate criteria. On a single occurrence a large abrupt input needed to aggressively capture the target led to divergent oscillations. The configuration was therefore rated as uncontrollable. The evaluation pilot pointed out that with a less demanding task or at a lower pilot gain this last handling quality deficiency would have been undetected.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C26.
3. A "-" indicates no rating was given.

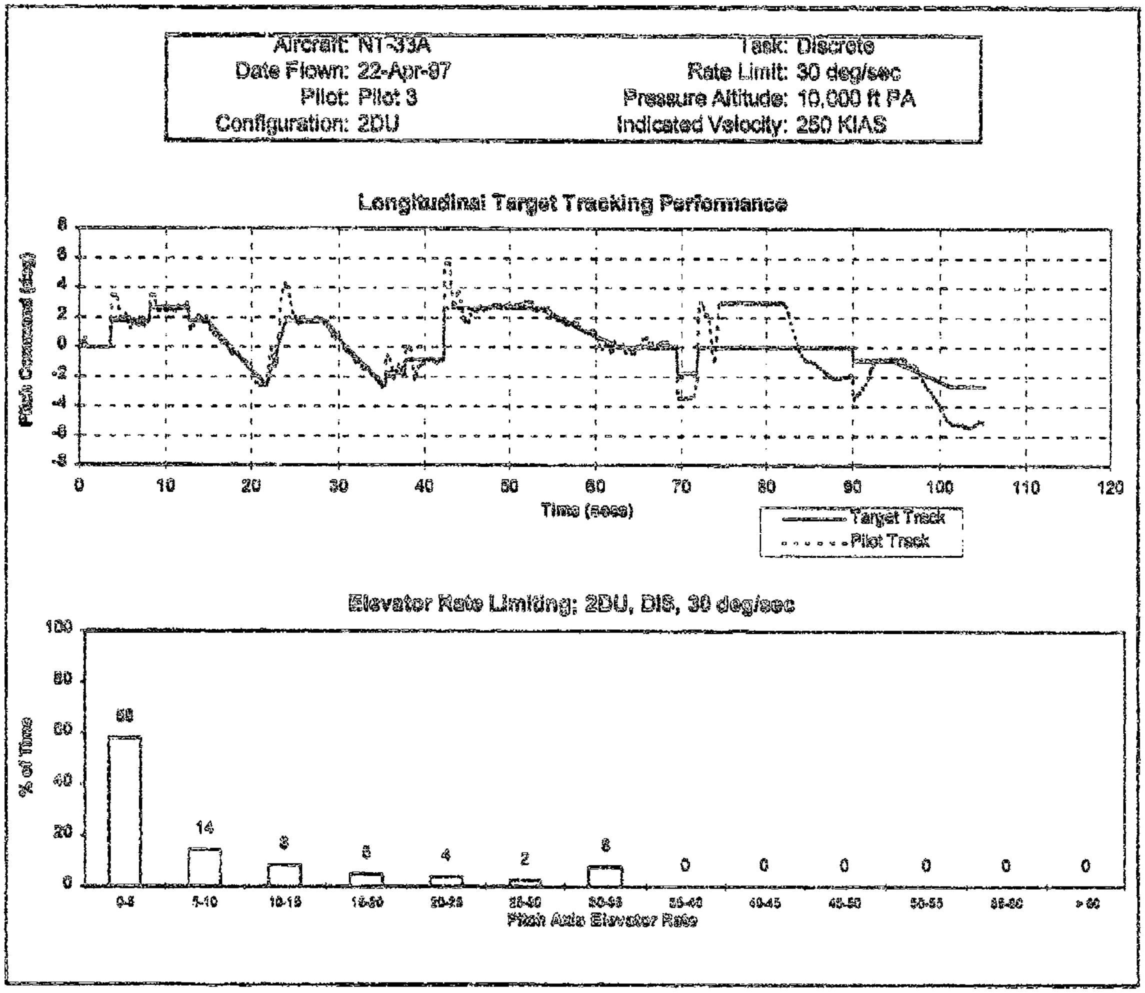

Figure C26 Representative Flight Test Result 2DU, Rate Limit of 30 Degrees Per Second, Discrete Task, Pilot 3

Table C53
PILOT COMMENTS FOR 2DU, RATE LIMIT OF 30 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2DU	Rate Limit: 30 degrees per second	Tracking Task: Discrete	
Pilot - Sortie(s)	Pilot 1 - 9	Pilot 2 - Not Flown	Pilot 3 - 8*
Cooper-Harper Ratings	9	Not Flown	10
PIO Ratings	5	Not Flown	5
AIRCRAFT			
Initial Response	Fast	N/A	Responsive
Steady-State Response	Responsive	N/A	Responsive
Predictable	No	N/A	No
Gross Acquisition	Difficult	N/A	Difficult
Fine Tracking	Desired	N/A	N/A
PILOT INTERFACE			
Control Harmony	Good	N/A	Good
Stick Forces	Low to medium	N/A	Medium
Compensation	Minimal (for Fine Tracking) to considerable (for Gross Acquisition)	N/A	Moderate to considerable (during oscillations)
Workload	Minimal (for Fine Tracking) to intolerable (for Gross Acquisition)	N/A	Tolerable to intolerable
Was there a PIO? Easily Induced?	Yes Yes	N/A	Yes No
COMMENTS			
Good Characteristics	Tight feeling in fine tracking.	N/A	Good, quick initial response (HQ deficiency were masked).
Bad Characteristics	Got quickly out of phase during even low gain large amplitude maneuvers.	N/A	Unpredictable steady-state response (2 to 3) oscillations, on a big pull - divergent oscillations.

Notes: 1. An "*" indicates test point plotted in Figure C26.
2. N/A - not applicable.

Table C54
SUMMARY 2DU, RATE LIMIT OF 40 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2DU	Rate Limit: 40 degrees per second	Tracking Task: Discrete
Cooper-Harper Ratings: 10 ‖ 10* ‖ 10	PIO Ratings: 5 ‖ 6* ‖ 5	
Overall Evaluation	The aircraft initial pitch response appeared to be fast, while the steady-state response was generally considered adequate to accomplish the task. The aircraft could track well at low pilot gain and steady conditions within the desired performance criteria with moderate compensation and tolerable workload. However, during aggressive pulls or abrupt captures the aircraft response appeared to lag the pilot input and divergent oscillations started. Pilots liked the fine tracking characteristics of the aircraft at low gain, but the gross acquisition response to aggressive inputs was clearly objectionable, therefore an overall uncontrollable rating was given.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C27.

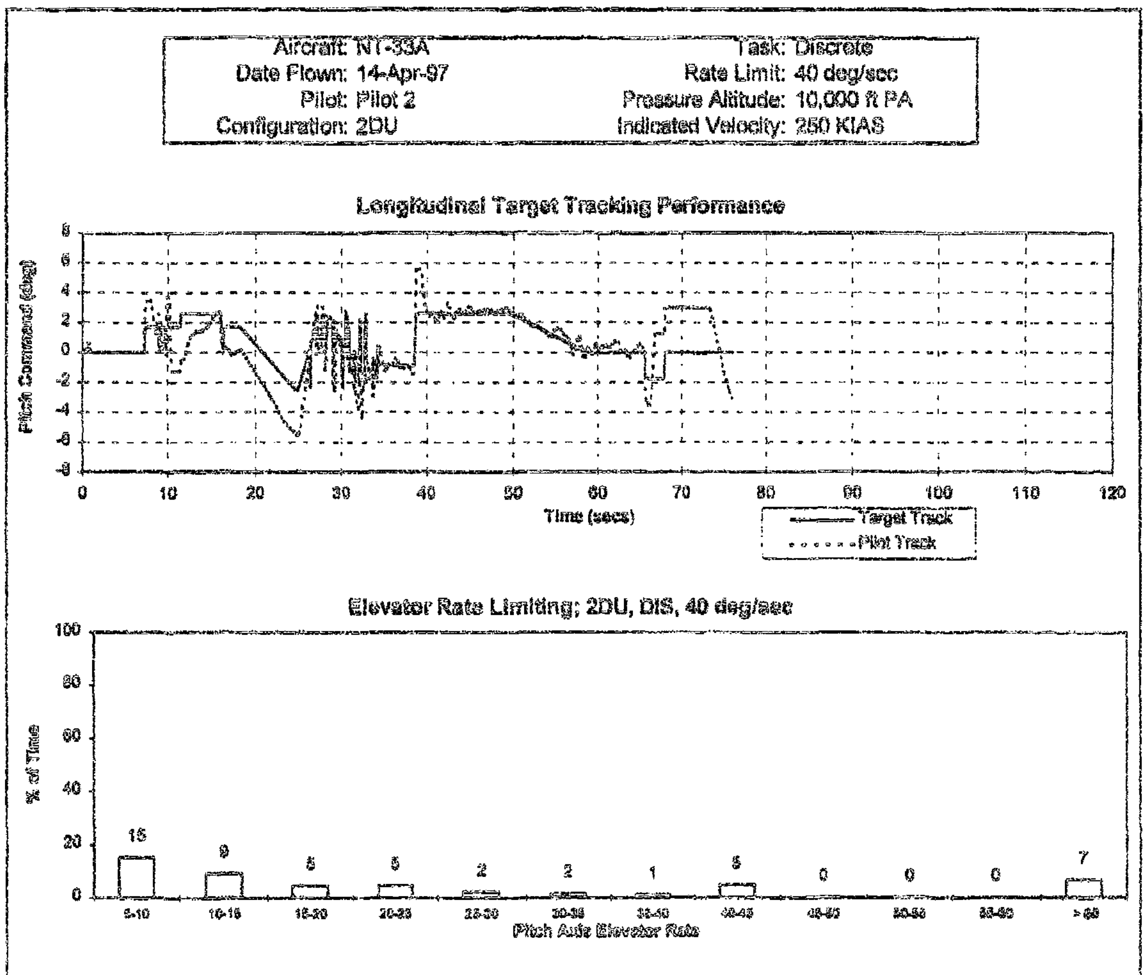

Figure C27 Representative Flight Test Result 2DU, Rate Limit of 40 Degrees Per Second, Discrete Task, Pilot 2

Table C55
PILOT COMMENTS FOR 2DU, RATE LIMIT OF 40 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2DU	Rate Limit: 40 degrees per second		Tracking Task: Discrete
Pilot - Sortie(s)	Pilot 1 - 4	Pilot 2 - 2*	Pilot 3 - 3
Cooper-Harper Ratings	10 (No problem at low gain/amplitude)	10 (For gross acquisition)	10
PIO Ratings	5	6	5
AIRCRAFT			
Initial Response	Fast(Overly responsive)	Fast	Responsive
Steady-State Response	Responsive	Fast	Responsive
Predictable	Yes (Fine) No (Kind of a cliff in performance)	No	Yes
Gross Acquisition	Difficult	Difficult	Easy
Fine Tracking	Desired	Desired (During loaded tracking OK. Problem hidden.)	Desired
PILOT INTERFACE			
Control Harmony	Good	Poor	Good
Stick Forces	Low to Medium (Good Feeling)	Low to Medium (Feels touchy in gross acquisition)	Medium
Compensation	Minimal (Fine) Considerable (Gross)	Considerable	Moderate (High side)
Workload	Minimal (Fine) Intolerable (Gross)	Tolerable (While tracking) Intolerable (During gross acquisition)	Tolerable (High side)
Was there a PIO? Easily Induced?	Yes Yes (Large amplitude, aggressive input)	Yes Yes (For gross acquisition)	Yes No
COMMENTS			
Good Characteristics	Fine track excellent. Flyable low gain.	Tracks well during loaded turns. Small corrections and small oscillations back to tracking.	Tracking is good under steady conditions.
Bad Characteristics	Gross acquisition at high gain seemed to lag. Led to divergent PIO.	Gross acquisition - large jump + or - results in divergent PIO. Flight pubs airborne momentarily -g variable stability system dump.	Jerky initial response. Abrupt captures start a divergent PIO.

Note: An "*" indicates test point plotted in Figure C27.

Table C56
SUMMARY 2DU, RATE LIMIT OF 50 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2DU	Rate Limit: 50 degrees per second	Tracking Task: Discrete
Cooper-Harper Ratings: 5/9 ‖ 10 ‖ 10*	PIO Ratings: 4/4 ‖ 5 ‖ 5*	
Overall Evaluation	The initial impression was of a very good, solid, fine tracking airplane with slightly jerky initial pitch response. However gross acquisition following big target steps caused pronounced overshoots and in two out of four evaluations a divergent PIO. In one evaluation a large amplitude aggressive input caused a non-divergent PIO. In general this handling quality deficiency was not immediately apparent to the evaluation pilots that at first, had the impression to be flying a very good aircraft until a larger or more aggressive input was required.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3. 3. An "*" indicates test point plotted in Figure C28.
2. A "/" separates multiple ratings by the same pilot.

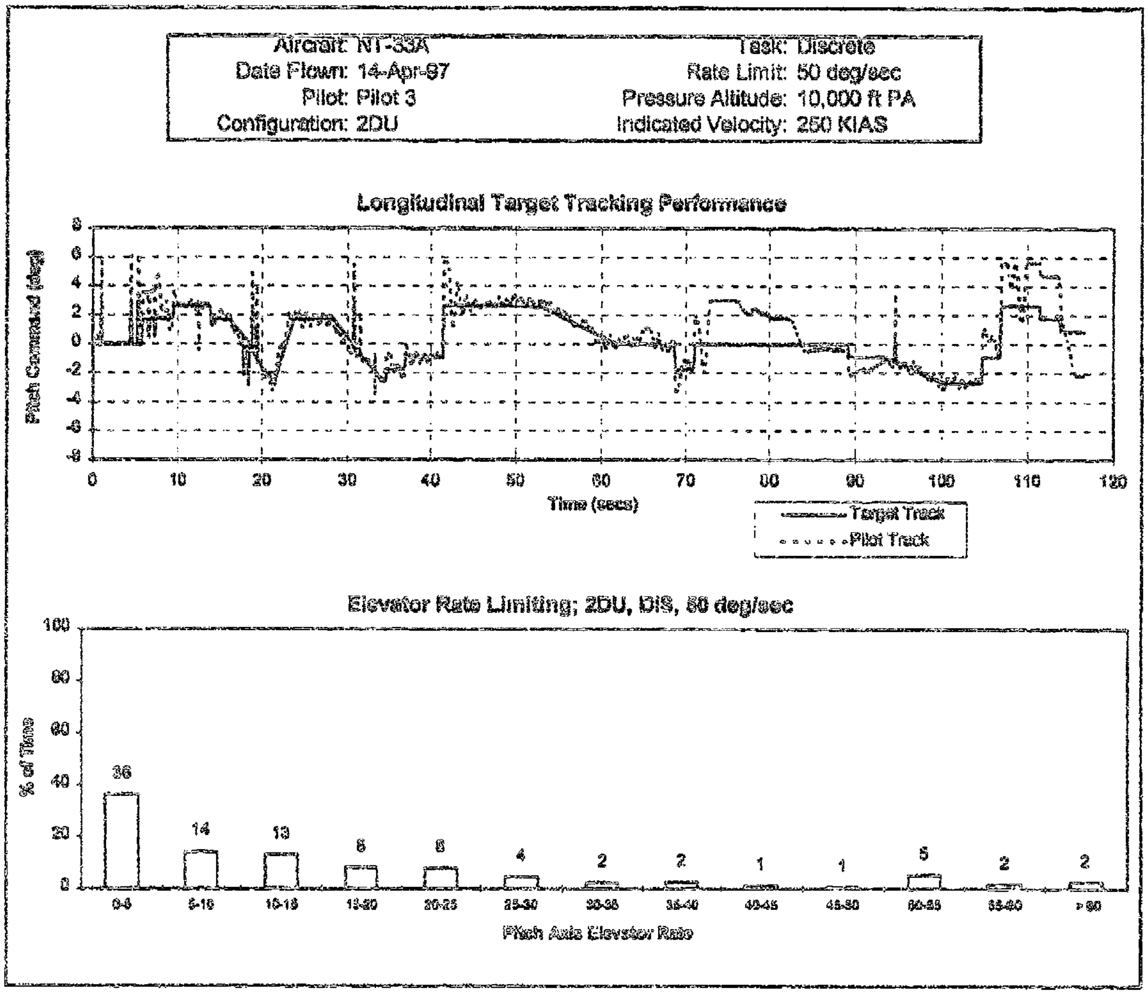

Figure C28 Representative Flight Test Result 2DU, Rate Limit of 50 Degrees Per Second, Discrete Task, Pilot 3

Table C57
PILOT COMMENTS FOR 2DU, RATE LIMIT OF 50 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2DU	Rate Limit: 50 degrees per second	Tracking Task: Discrete	
Pilot - Sortie(s)	Pilot 1 - 1,4	Pilot 2 - 2	Pilot 3 - 3*
Cooper-Harper Ratings	5/9	10	10
PIO Ratings	4 (due to one small portion of the task)/4	5 (discussion; go with 5, divergent tendency)	5
AIRCRAFT			
Initial Response	Responsive/Fast (springy)	Fast	Responsive
Steady-State Response	Responsive/Responsive	Responsive	Responsive
Predictable	Yes/Yes (Fine) No (Gross Acquisition; amplitude lagged input)	Yes (small corrections) No (Gross Acquisition)	No
Gross Acquisition	Easy to difficult (due to overshoot on aggressive capture)/Difficult	Difficult (too much divergent tendency)	Easy (for small steps) Difficult (for large steps)
Fine Tracking	Desired/Desired	Desired (small oscillation about target)	Adequate
PILOT INTERFACE			
Control Harmony	Excellent (with increasing g)/Good	Poor to good	Good
Stick Forces	Low (with increasing g)/Low	Medium	Medium
Compensation	Minimal (Fine) Moderate (Gross)/Minimal (Fine) Moderate (Gross)	Minimal to moderate (Fine Tracking)	Moderate +
Workload	Minimal (Fine) Tolerable (Gross)/ Minimal (Fine) Tolerable (Gross)	Intolerable (Gross Acquisition)	Tolerable
Was there a PIO? Easily Induced?	Yes (very little)/Yes No/Yes	Yes Yes (with Gross Acquisition)	Yes No (only big pull excited it)
COMMENTS			
Good Characteristics	Excellent fine track. Solid fine track at high-g. Tripped variable stability system during aggressive capture track. Still solid/Fine tracking outstanding.	Fine tracking desired performance with minimal compensation. Tracks real nice.	Fine tracking good if target stable.
Bad Characteristics	Initial captures one to two overshoots. Small PIO with very aggressive input to very close control/Springy. Lightly damped. Large amplitude aggressive input leads to non-divergent PIO.	Bad airplane very well masked. Gross acquisition following jump unsatisfactory. Two divergent oscillations. Safety pilot dumped.	Sensitive, jerky initial response. Pronounced overshoots. Divergent PIO when abrupt tight control initiated. Well masked bad configuration.

Notes: 1. A "/" separates multiple ratings by the same pilot.
2. An "*" indicates test point plotted in Figure C28.

Table C58

SUMMARY 2DU, RATE LIMIT OF 60 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2DU	Rate Limit: 60 degrees per second	Tracking Task: Discrete
Cooper-Harper Ratings: 8 ‖ 4/3 ‖ 10/10*	PIO Ratings: 4 ‖ 3/2 ‖ 5/5*	
Overall Evaluation	The initial impression was of a very good aircraft with a quick, even if slightly jerky, initial pitch response. Fine tracking quality was generally good with no undesirable motions and allowed to achieve desired performance in all the evaluations. However during aggressive, large amplitude, gross acquisition maneuvering, the airplane wound-up and diverged in pitch in two occasions out of five evaluations. Other objectionable characteristics were an annoying small pitch bobble around the target during gross acquisition and the tendency to grossly overshoot the target during reversals. Overall the configuration had a cliff-type handling quality deficiency very well masked during the entire task.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3. 3. An "*" indicates test point plotted in Figure C29.
2. A "/" separates multiple ratings by the same pilot.

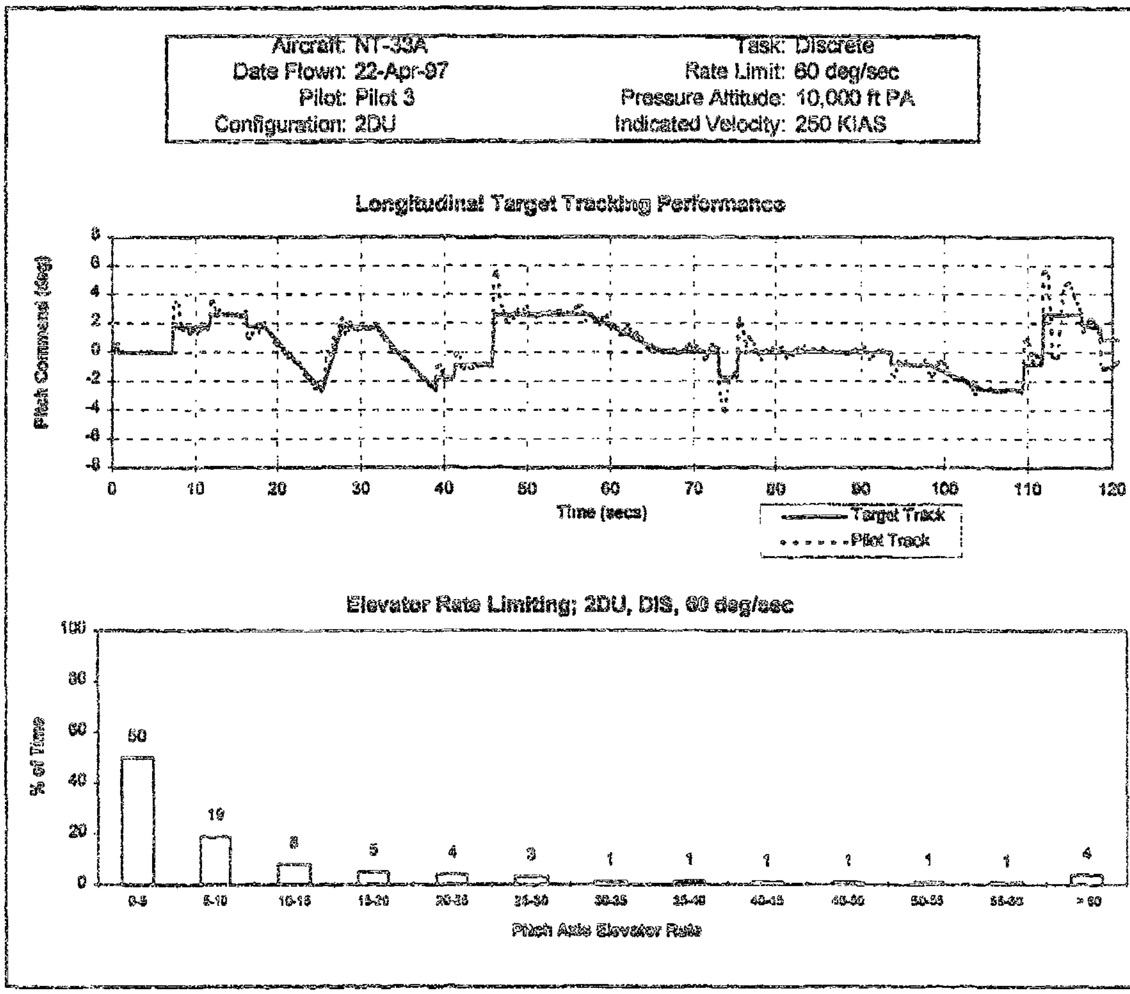

Figure C29 Representative Flight Test Result 2DU, Rate Limit of 60 Degrees Per Second, Discrete Task, Pilot 3

Table C59

PILOT COMMENTS FOR 2DU, RATE LIMIT OF 60 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2DU	Rate Limit: 60 degrees per second	Tracking Task: Discrete	
Pilot - Sortie(s)	Pilot 1 - 4	Pilot 2 - 5/7	Pilot 3 - 6/8*
Cooper-Harper Ratings	8	4/3	10/10
PIO Ratings	4	3/2	5/5
AIRCRAFT			
Initial Response	Responsive	Fast/Responsive	Responsive (jerky; well masked)/Responsive
Steady-State Response	Responsive	Slow to responsive/Responsive	Responsive/Responsive
Predictable	Yes (usually) No (high gain, high compensation)	Yes/Yes	Yes (up to the point where it went unstable)/Yes
Gross Acquisition	Easy (usually) Difficult (high gain high compensation)	Easy and difficult (1 to 2 overshoot on gross acquisition)/Easy	Easy (up to the point where it went unstable)/Easy
Fine Tracking	Adequate	Desired/Desired	Desired (up to the point where it went unstable)/Desired
PILOT INTERFACE			
Control Harmony	N/A	Good/Good	Good/Good
Stick Forces	Medium (stiff stick)	Medium/Medium	Medium/Medium
Compensation	Moderate	Minimal (Fine Tracking) Moderate (Gross Acquisition)/Minimal	Moderate/Moderate
Workload	Tolerable	Tolerable/Minimal	Tolerable/Tolerable
Was there a PIO? Easily Induced?	Yes (tendency) No	No/No No/No	Yes/Yes No/No
COMMENTS			
Good Characteristics	Not bad feeling, adequate achievable.	Tracks OK under g/Initial gross acquisition is good, responsive, tracks well under g.	Initial impression is of a good aircraft quick and predictable, but on the jerky side/Tracking quality appeared to be good initially with no undesirable motions.
Bad Characteristics	Heavy stick, nose lags desired input, aggressive inputs lead to PIO.	Sensitive to touch, variable stability system disengage under aerodynamic buffet, feels like limited control to capture high acquisition, some annoying deficiencies with desired performance/Small pitch bobble about target with gross acquisition, excessive nose-up during reversal, does not unload easily- still get pitch-up, compromise in tracking.	It diverged during a big pull in a quick and surprising way; cliff-type handling quality deficiency/During the last big pull of the task the aircraft wound up, encountered aerodynamic buffet and departed in pitch. Cliff-type handling quality deficiency. Very well masked during the entire task.

Notes: 1. A "/" separates multiple ratings by the same pilot.
2. An "*" indicates test point plotted in Figure C29.
3. N/A - not applicable.

Table C60
SUMMARY 2DU, RATE LIMIT OF 157 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2DU	Rate Limit: 157 degrees per second	Tracking Task: Discrete
Cooper-Harper Ratings: - ‖ 2 ‖ 5/4*	PIO Ratings: - ‖ 2 ‖ 3/2*	
Overall Evaluation	The airplanes initial pitch response was very quick and slightly faster than the steady-state response. It was described as "springy" and "nervous" by one of the evaluation pilots. Gross acquisition was overall easy but for aggressive inputs quick but rapidly damped small amplitude oscillations were noted. Fine tracking was within desired performance criteria with tolerable workload and moderate compensation. During pulls under higher g two annoying pitch rate oscillations were noted while gross acquiring the target. The aircraft handling qualities were assessed Level 1 in one evaluation, and Level 2 in the remaining two mainly because the jerkiness of the initial pitch response and the pitch rate oscillations under g that were assessed as minor but annoying deficiencies.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. A "/" separates multiple ratings by the same pilot.
3. An "*" indicates test point plotted in Figure C30.
4. A "-" indicates no rating was given.

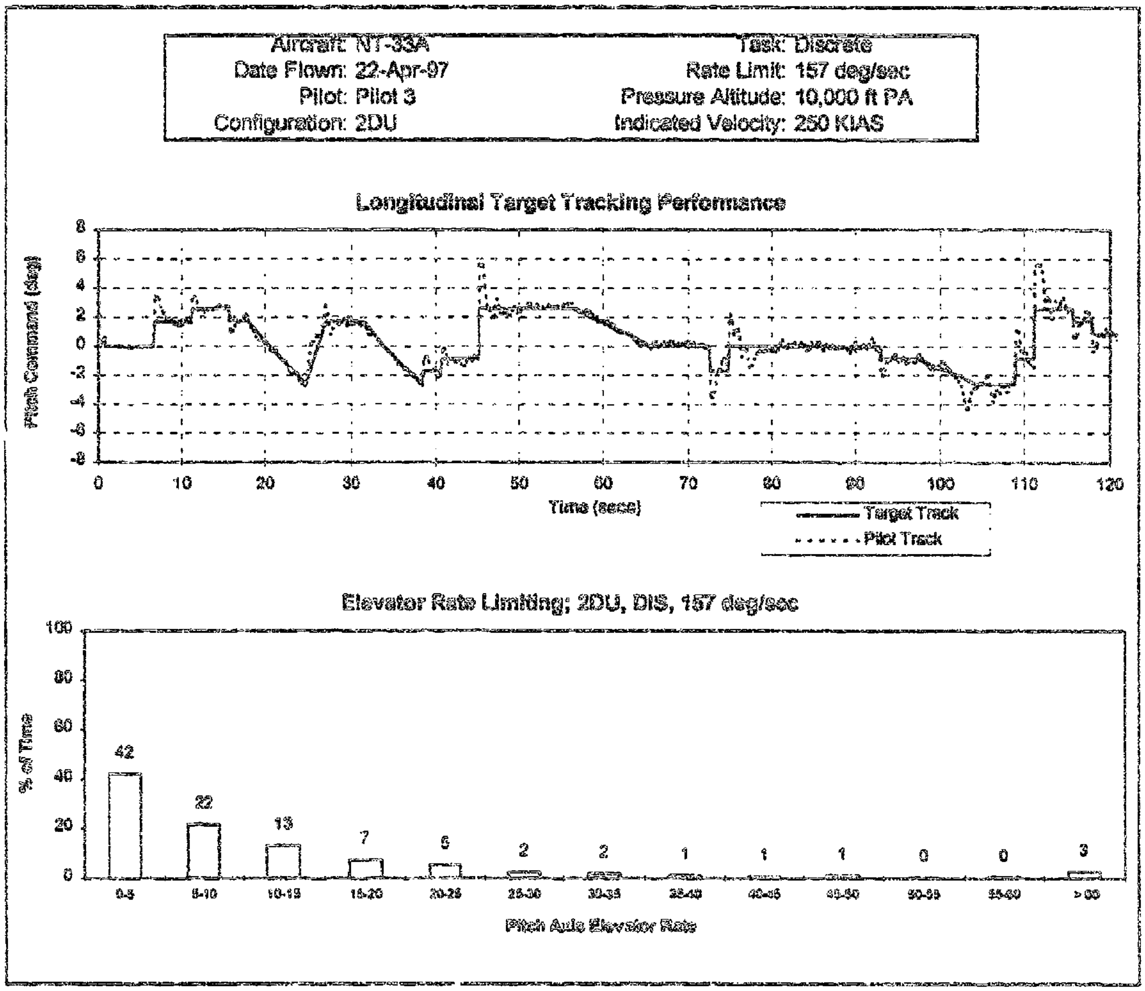

Figure C30 Representative Flight Test Result 2DU, Rate Limit of 157 Degrees Per Second, Discrete Task, Pilot 3

Table C61
PILOT COMMENTS FOR 2DU, RATE LIMIT OF 157 DEGREES PER SECOND, DISCRETE TASK

Aircraft Configuration: 2DU	Rate Limit: 157 degrees per second	Tracking Task: Discrete	
Pilot - Sortie(s)	Pilot 1 - Not Flown	Pilot 2 - 7	Pilot 3 - 6/8*
Cooper-Harper Ratings	Not Flown	2	5/4
PIO Ratings	Not Flown	2	3/2
AIRCRAFT			
Initial Response	N/A	Responsive	Fast (jerky)/Responsive
Steady-State Response	N/A	Responsive	Responsive/Responsive
Predictable	N/A	Yes	Yes (but when aggressive tended to oscillate)/Yes (under moderate g loadings)
Gross Acquisition	N/A	Easy	Easy/Easy
Fine Tracking	N/A	Desired (under g)	Desired/Desired
PILOT INTERFACE			
Control Harmony	N/A	Good	Good/Good
Stick Forces	N/A	Medium	Low/Medium
Compensation	N/A	Minimal	Moderate/Moderate
Workload	N/A	Minimal	Tolerable/Tolerable
Was there a PIO? Easily Induced?	N/A	No No	No/No No/No
COMMENTS			
Good Characteristics	N/A	Flew fairly well, satisfactory without improvement.	Good fine tracking but I wasn't confident in giving it a 4 so I decided for a 5/Good tracking under moderate-g (below 2 g) loading.
Bad Characteristics	N/A	One to two overshoot initial acquisition, small bobbling about target under low-g, large bobble with large acquisition, stopped short on gross acquisition.	Two oscillations for aggressive tracking, oscillations were quick and surprised the pilot, they damped out quickly but were surprising, overall a springy and "nervous" configuration/At higher g values of two annoying pitch rate oscillations (minor but annoying deficiency).

Notes: 1. A "/" separates multiple ratings by the same pilot.
2. An "*" indicates test point plotted in Figure C30.
3. N/A - not applicable.

Table C62

SUMMARY 2DU, RATE LIMIT OF 20 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2DU	Rate Limit: 20 degrees per second	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 10 ‖ 10 ‖ 10*	PIO Ratings: 6 ‖ 6 ‖ 6*	
Overall Evaluation	This airplane was characterized by a fast, initial. and steady-state pitch response. The aircraft was consistently rated uncontrollable due to the fact that just entering the control loop with normal inputs caused divergent oscillations. Releasing or freezing the control stick did not stop the oscillations. The configuration was clearly unflyable.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C31.

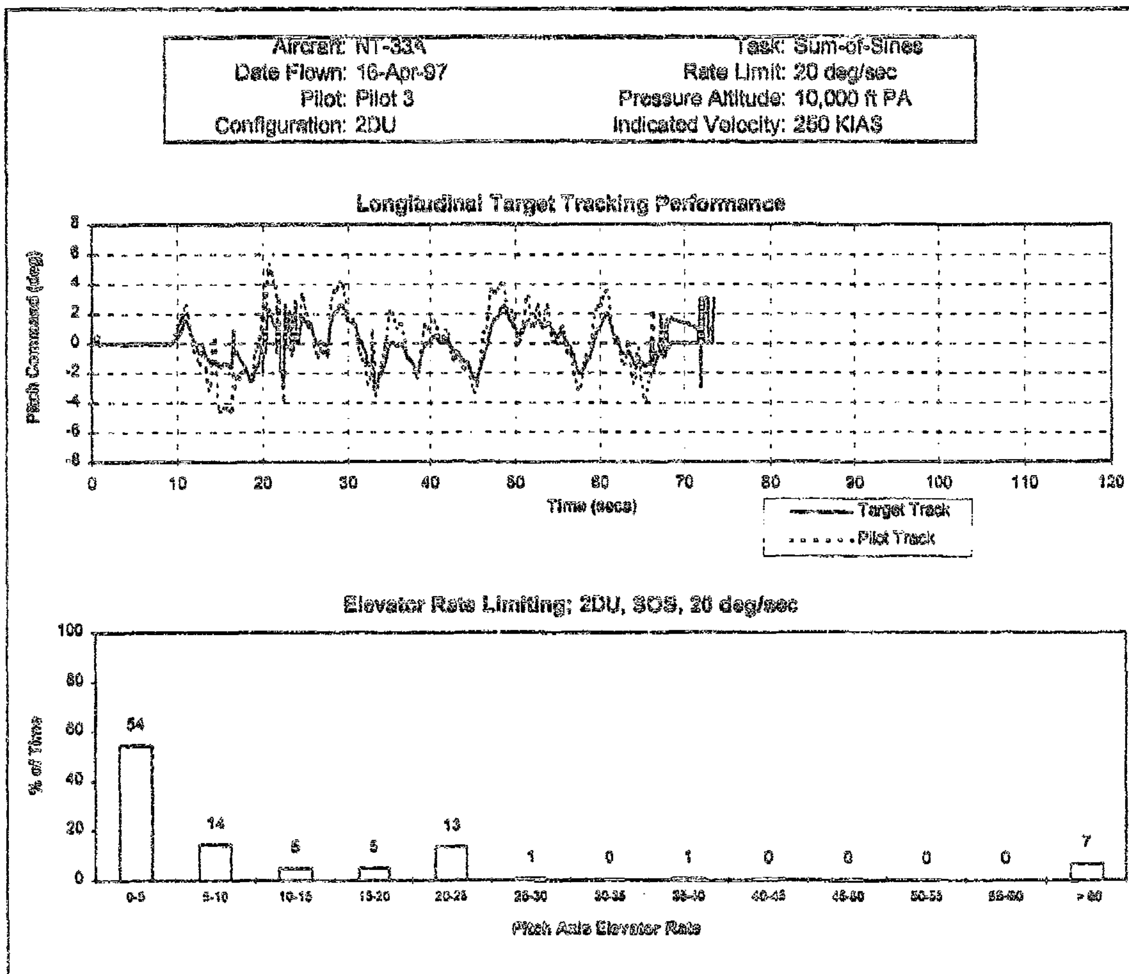

Figure C31 Representative Flight Test Result 2DU, Rate Limit of 20 Degrees Per Second, Sum-of-Sines Task, Pilot 3

Table C63
PILOT COMMENTS FOR 2DU, RATE LIMIT OF 20 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2DU	Rate Limit: 20 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 1	Pilot 2 - 2	Pilot 3 - 6*
Cooper-Harper Ratings	10	10	10
PIO Ratings	6	6	6
AIRCRAFT			
Initial Response	Fast	Fast	Responsive
Steady-State Response	Fast	Fast	Slow
Predictable	No	No	No
Gross Acquisition	Impossible	Unsatisfactory	Difficult
Fine Tracking	Not possible	Adequate	N/A
PILOT INTERFACE			
Control Harmony	N/A	Poor	N/A
Stick Forces	Low	Medium	Medium
Compensation	Considerable	Considerable	Considerable
Workload	Intolerable	Intolerable	Intolerable
Was there a PIO? Easily Induced?	Yes Yes	Yes Yes	Yes Yes
COMMENTS			
Good Characteristics	None	None	None
Bad Characteristics	Unable to complete task, any input drove PIO, opening control loop does not solve problem, unflyable.	Divergent, dumped by safety pilot, bad airplane hidden during small correction tracking, large jumps lead to divergence, could not stop by freezing or release.	Worst configuration so far, as soon as I entered the control loop I got divergent PIO, completely unflyable

Notes: 1. An "*" indicates test point plotted in Figure C31.
2. N/A - not applicable.

Table C64
SUMMARY 2DU, RATE LIMIT OF 30 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2DU	Rate Limit: 30 degrees per second	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 8/3 ‖ 2 ‖ 9/8*	PIO Ratings: 4/2 ‖ 1 ‖ 4/3*	
Overall Evaluation	This aircraft configuration appeared initially good to perform the task with slightly fast initial but responsive steady-state response. Predictability and ease of control were not questionable with moderately aggressive pilot inputs. In fact two out of five evaluations assessed the aircraft as a solid, comfortable platform to fly with minimal compensation and tolerable workload. However, when the aircraft was flown very aggressively undesired motions and in one evaluation a PIO were started. The PIO could be stopped by releasing the controls. Overall the configuration handling qualities were evaluated Level 1 and Level 3 by one evaluation pilot, Level 1 by another pilot and Level 3 twice by the third evaluation pilot. This ample variation in the ratings could be attributed to a cliff-type handling quality deficiency that was highlighted only when the task required large amplitude and very aggressive corrections.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3. 3. An "*" indicates test point plotted in Figure C32.
2. A "/" separates multiple ratings by the same pilot.

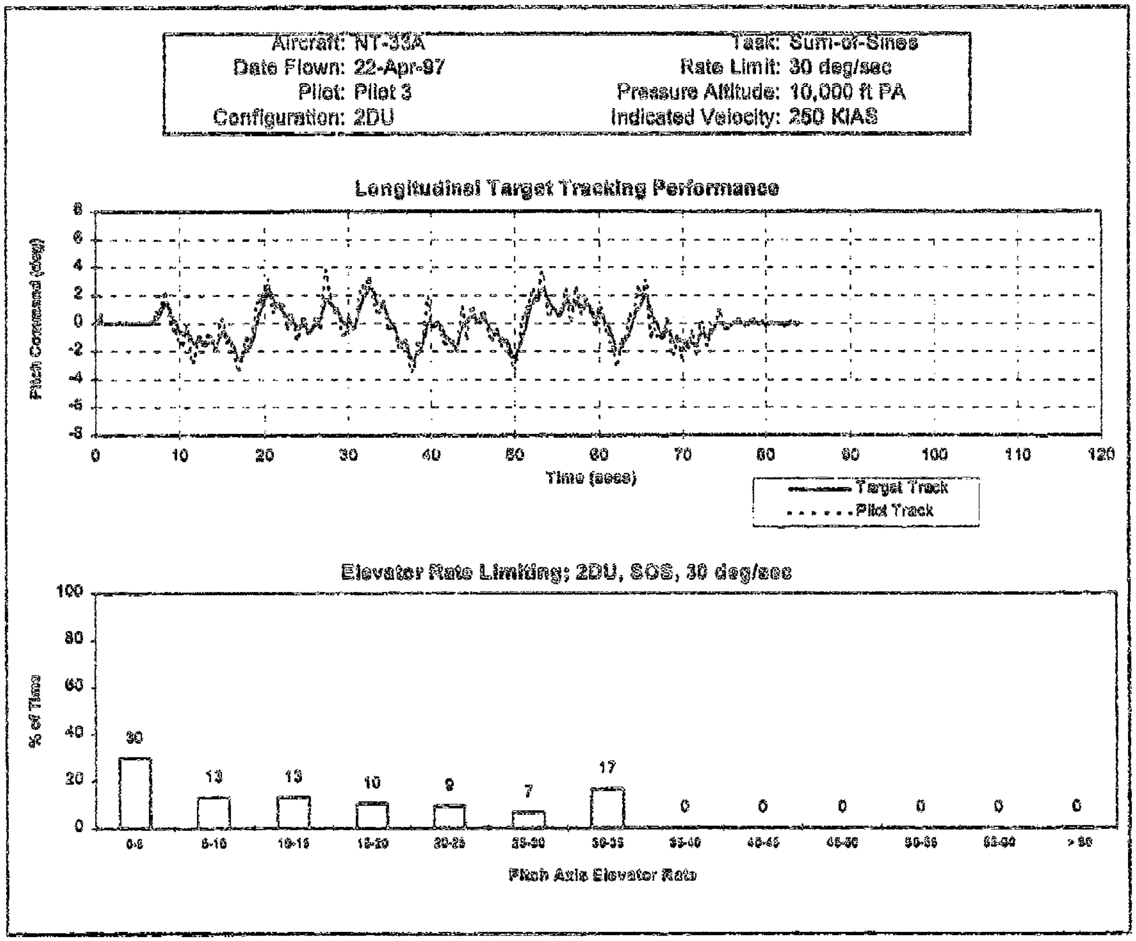

Figure C32 Representative Flight Test Result 2DU, Rate Limit of 30 Degrees Per Second, Sum-of-Sines Task, Pilot 3

Table C65
PILOT COMMENTS FOR 2DU, RATE LIMIT OF 30 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2DU	Rate Limit: 30 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 9/9	Pilot 2 - 5	Pilot 3 - 6/8°
Cooper-Harper Ratings	8/3	2	9/8
PIO Ratings	4/2	1	4/3
AIRCRAFT			
Initial Response	Fast/Responsive	Responsive	Responsive/Responsive
Steady-State Response	Responsive/Responsive	Responsive	Responsive/Responsive
Predictable	Yes (Fine) No (large amplitude)/Yes	Yes	No/No
Gross Acquisition	Difficult/Easy	Easy	Difficult/Difficult
Fine Tracking	Desired/No rating	Adequate to desired	Adequate/No rating
PILOT INTERFACE			
Control Harmony	N/A/N/A	Good	N/A/N/A
Stick Forces	Low/Low	Medium	Medium/Medium
Compensation	Minimal (Fine) to considerable (Gross Acquisition)/Minimal (Fine) to moderate (Gross Acquisition)	Minimal	Considerable/Moderate
Workload	Minimal (Fine) to intolerable (Gross Acquisition)/Minimal (Fine) to tolerable (Gross)	Minimal	Intolerable/Tolerable (high side)
Was there a PIO? Easily Induced?	Yes/No Yes (with routine gain)/No	No No	Yes/No No (stopped by releasing the controls)/No (undesired oscillations)
COMMENTS			
Good Characteristics	Fine Tracking OK/Good fine track. Pretty good airplane.	No oscillations about the target. Good steady tracking. No tendency to bobble with aggressive in the loop. Nice airplane.	Initially good tracking. Catches the pilot by surprise when it eventually degrees rades/None.
Bad Characteristics	Overly fast initial response led to large overshoots. Easy to get out of phase. Controllability was in question./Slightly oversensitive. Drove some small overshoots.	N/A	Cliff-type degrees rotation of handling quality with high gain inputs./Pitch oscillations are quick and compromised task performance to the point where adequate performance could not be achieved and control might have been lost at high pilot gains.

Notes: 1. A "/" separates multiple ratings by the same pilot.
2. An "°" indicates test point plotted in Figure C32.
3. N/A - not applicable.

Table C66
SUMMARY 2DU, RATE LIMIT OF 40 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2DU	Rate Limit: 40 degrees per second	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 5 ‖ 3/4* ‖ 6	PIO Ratings: 3 ‖ 2/3* ‖ 4	
Overall Evaluation	The initial and steady-state pitch response were assessed "abrupt" and "tight" with small overshoots and oscillations about the target. For bigger control inputs out-of-phase oscillations were induced and could be eliminated by reducing the pilot gains and aggressiveness. Overall the aircraft handling qualities were consistently rated Level 2 with occasional PIO tendencies.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. A "/" separates multiple ratings by the same pilot.
3. An "*" indicates test point plotted in Figure C33.

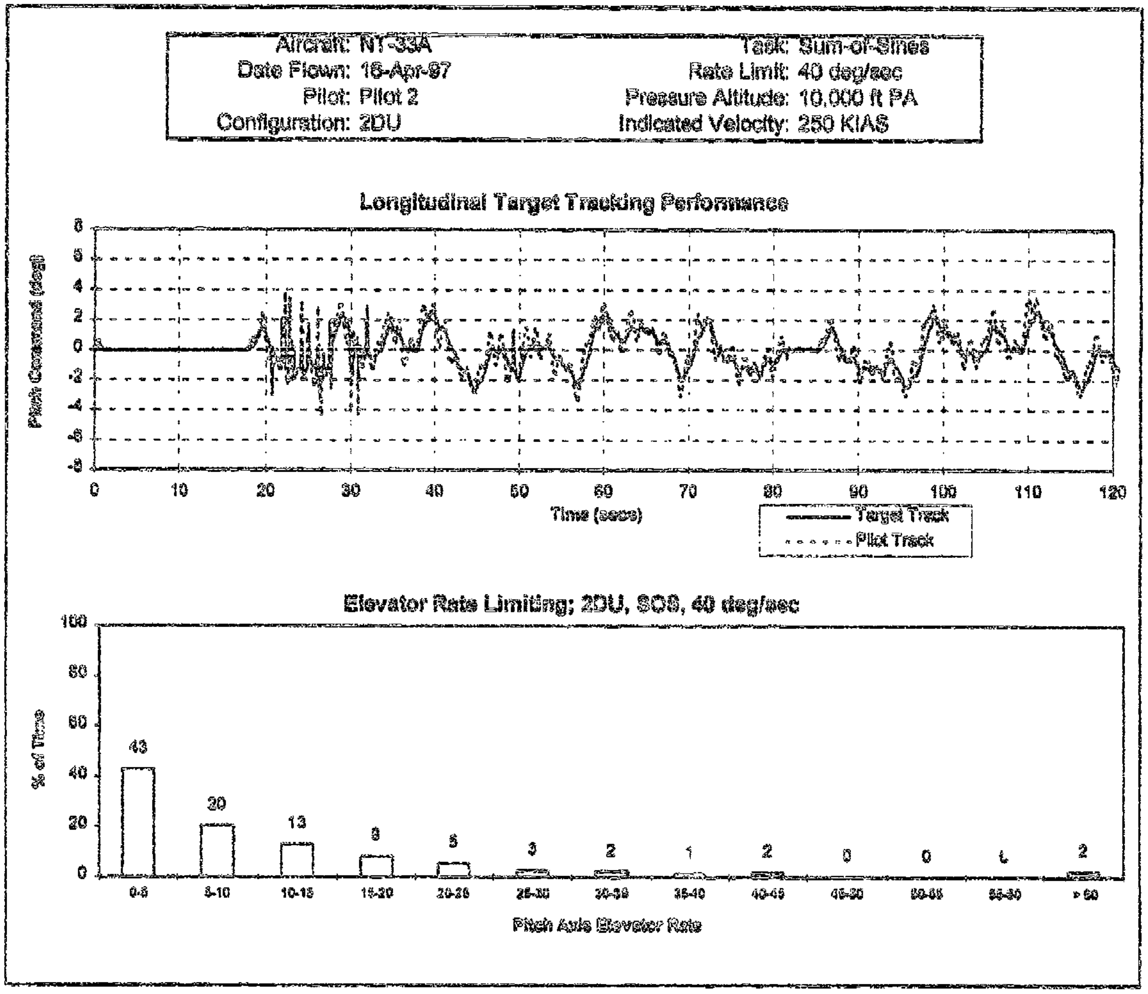

Figure C33 Representative Flight Test Result 2DU, Rate Limit of 40 Degrees Per Second, Sum-of-Sines Task, Pilot 2

Table C67
PILOT COMMENTS FOR 2DU, RATE LIMIT OF 40 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2DU	Rate Limit: 40 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 1	Pilot 2 - 5,7*	Pilot 3 - 3
Cooper-Harper Ratings	5 (close to 4)	3/4 (increase workload and compensation to increase performance)	6
PIO Ratings	3	2/3	4
AIRCRAFT			
Initial Response	Responsive	Fast/Responsive	Responsive
Steady-State Response	Responsive	Responsive/Responsive	Responsive
Predictable	Yes	Yes/Yes	No
Gross Acquisition	Slightly difficult	Easy (one to two overshoots) within adequate criteria	Difficult
Fine Tracking	Adequate	Desired/Adequate	Adequate
PILOT INTERFACE			
Control Harmony	N/A	Good/Good	N/A
Stick Forces	Medium	Medium/Medium	Medium
Compensation	Moderate for desired	Minimal to moderate/Minimal	Moderate
Workload	Tolerable	Tolerable/Tolerable	Tolerable (on the high side)
Was there a PIO? Easily Induced?	No No	No/No No/No	No Yes (unwanted oscillations were easily induced.)
COMMENTS			
Good Characteristics	Not a bad jet. Only slightly over sensitive.	Small overshoots did not prevent accomplishment of the task/Gross Acquisition within adequate criteria.	N/A
Bad Characteristics	Capture overly sensitive (two to three overshoots). Too "tight" in pitch. Initial turbulence tainted first 10 to 15 seconds.	Oscillating about the target. Small overshoots-small captures/Abrupt initial response. One to two overshoots on gross acquisition. Pitch bobbling about target during tracking. Extra compensation required to eliminate.	Jerky initial response. Out of phase oscillations when the target makes bigger jumps.

Notes: 1. A "/" separates multiple ratings by the same pilot.
2. An "*" indicates test point plotted in Figure C33.
3. N/A - not applicable.

Table C68
SUMMARY 2DU, RATE LIMIT OF 50 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2DU	Rate Limit: 50 degrees per second	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 5* ‖ 4 ‖ 6	PIO Ratings: 4* ‖ 3 ‖ 3	
Overall Evaluation	The initial and steady-state pitch response were assessed "springy" and "unpredictable" to the point where one evaluation pilot described them as "uncomfortable." Undesirable motions were easily induced increasing pilot workload. For bigger control inputs in one evaluation a mild PIO was observed but could be easily eliminated by reducing pilot gains. Overall the aircraft handling qualities were consistently rated Level 2 with occasional PIO tendencies.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C34.

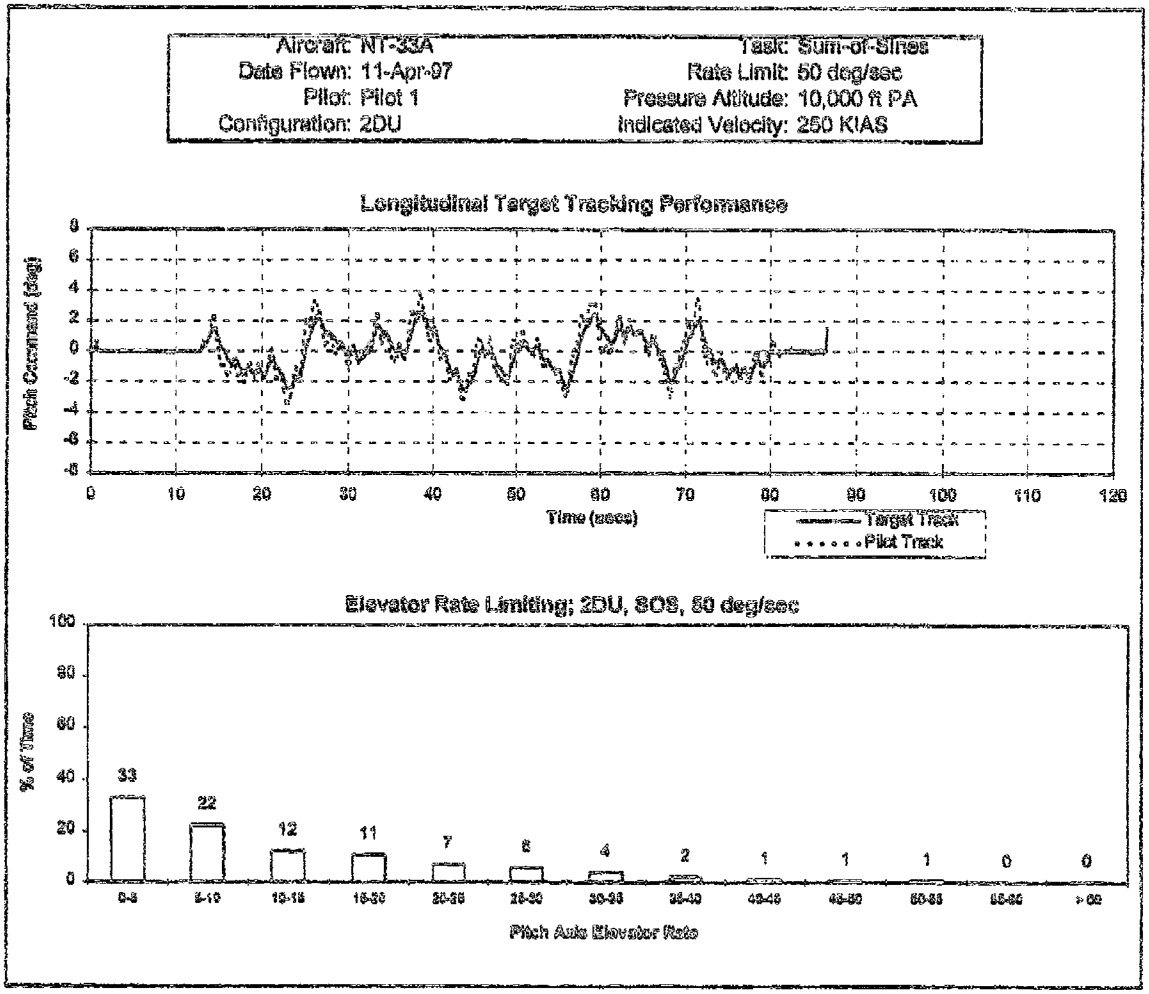

Figure C34 Representative Flight Test Result 2DU, Rate Limit of 50 Degrees Per Second, Sum-of-Sines Task, Pilot 1

Table C69
PILOT COMMENTS FOR 2DU, RATE LIMIT OF 50 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2DU	Rate Limit: 50 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 1*	Pilot 2 - 2	Pilot 3 - 6
Cooper-Harper Ratings	5	4	6
PIO Ratings	4	3	3
AIRCRAFT			
Initial Response	Responsive	Fast	Responsive (jerky)
Steady-State Response	Fast	Responsive	Responsive
Predictable	No	Yes	No
Gross Acquisition	Difficult (for adequate performance criteria)	Easy	Difficult
Fine Tracking	Adequate	Adequate	Adequate
PILOT INTERFACE			
Control Harmony	N/A	Good	N/A
Stick Forces	Medium	Medium	Low
Compensation	Moderate (Fine Tracking) Considerable (Gross Acquisition)	Moderate	Moderate+
Workload	Tolerable (for adequate performance criteria)	Tolerable	Tolerable+
Was there a PIO? Easily Induced?	Yes (very slight) Yes (driven by aggressiveness)	No No	No No
COMMENTS			
Good Characteristics	Flyable	None	None
Bad Characteristics	Abrupt inputs cause mild PIO, easily compensated for.	Pitch bobbles about the target while fine tracking increasing pilot workload, a bit too fast on initial response.	Initial pitch response springy and unpredictable, jerkiness makes this configuration uncomfortable for the pilot, undesirable motions were easily induced.

Notes: 1. An "*" indicates test point plotted in Figure C34.
2. N/A - not applicable.

Table C70
SUMMARY 2DU, RATE LIMIT OF 60 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2DU	Rate Limit: 60 degrees per second	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 3 ‖ 3/3* ‖ 5	PIO Ratings: 2 ‖ 2/2* ‖ 3	
Overall Evaluation	The aircraft felt responsive both in the initial and the steady-state response. This configuration was considered overall predictable in that desired performance criteria could be achieved on three out of four evaluations. One evaluation pilot noticed that at higher pilot gains the tracking performance degrees raded to adequate due to the onset of annoying undesirable motions. Overall the handling qualities of the aircraft were evaluated borderline between Level 1 and Level 2 with undesirable oscillations more evident when the pilot was tracking aggressively.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. A "/" separates multiple ratings by the same pilot.
3. An "*" indicates test point plotted in Figure C35.

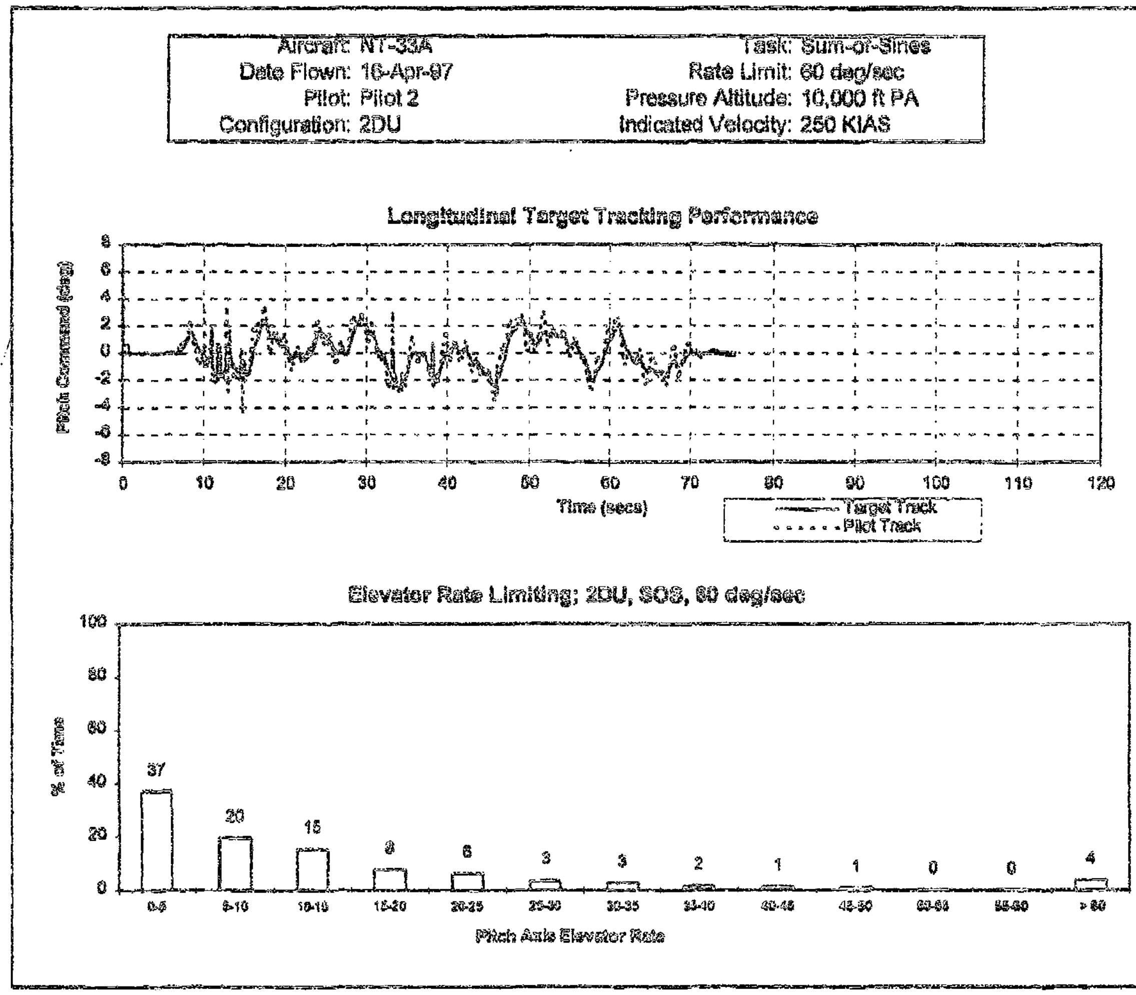

Figure C35 Representative Flight Test Result 2DU, Rate Limit of 60 Degrees Per Second, Sum-of-Sines Task, Pilot 2

Table C71
PILOT COMMENTS FOR 2DU, RATE LIMIT OF 60 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2DU	Rate Limit: 60 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 4	Pilot 2 - 5/7*	Pilot 3 - 6
Cooper-Harper Ratings	3	3/3	5
PIO Ratings	2	2/2	3
AIRCRAFT			
Initial Response	Responsive	Responsive/Responsive to fast	Responsive
Steady-State Response	Responsive	Responsive/Responsive	Responsive
Predictable	Yes	Yes/Yes	No
Gross Acquisition	Easy	Easy/Easy	Easy (for low gain tracking)
Fine Tracking	Desired	Desired/Desired	Adequate
PILOT INTERFACE			
Control Harmony	N/A	Good/Good	N/A
Stick Forces	Low (firm feel)	Medium/Medium	Medium
Compensation	Minimal	Minimal to moderate/Minimal	Moderate
Workload	Minimal+	Minimal to tolerable/Minimal	Tolerable+
Was there a PIO? Easily Induced?	No No	No/No No/No	No No
COMMENTS			
Good Characteristics	One small overshoot then no problem, nice feeling jet.	Gross Acquisition was good/Small acquisitions easily controllable, minimal compensation required to accommodate for springy feel.	None
Bad Characteristics	Slightly overly sensitive, very springy feeling, high frequency short period but were damped.	Small oscillations about the target during fine tracking, difficult to control without increase in compensation. Task performance was compromised slightly/Pitch bobbling about the target, slightly abrupt, springy with large acquisitions.	Quality of tracking is strongly dependent on pilot gains, unpredictable overall, undesirable motions easily induced.

Notes: 1. A "/" separates multiple ratings by the same pilot.
2. An "*" indicates test point plotted in Figure C35.
3. N/A - not applicable.

Table C72
SUMMARY 2DU, RATE LIMIT OF 157 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2DU	Rate Limit: 157 degrees per second	Tracking Task: Sum-of-Sines
Cooper-Harper Ratings: 3* ‖ - ‖ 3	PIO Ratings: 2* ‖ - ‖ 2	
Overall Evaluation	This airplane was characterized by a quick and "springy" initial pitch response while the steady-state pitch response was assessed good for the task. The pitch response was pleasantly predictable both at low and high pilot gains. Two to three small unwanted oscillations were noticed during aggressive tracking, but they were considered as a mildly objectionable deficiency as they did not affect task performance that was consistently within the desired criteria. The aircraft gave a fi[illegible] and comfortable feeling to the evaluation pilots and was considered overall good for the tested tracking task.	

Notes: 1. The order of ratings is Pilot 1 ‖ Pilot 2 ‖ Pilot 3.
2. An "*" indicates test point plotted in Figure C36.
3. A "-" indicates no rating was given.

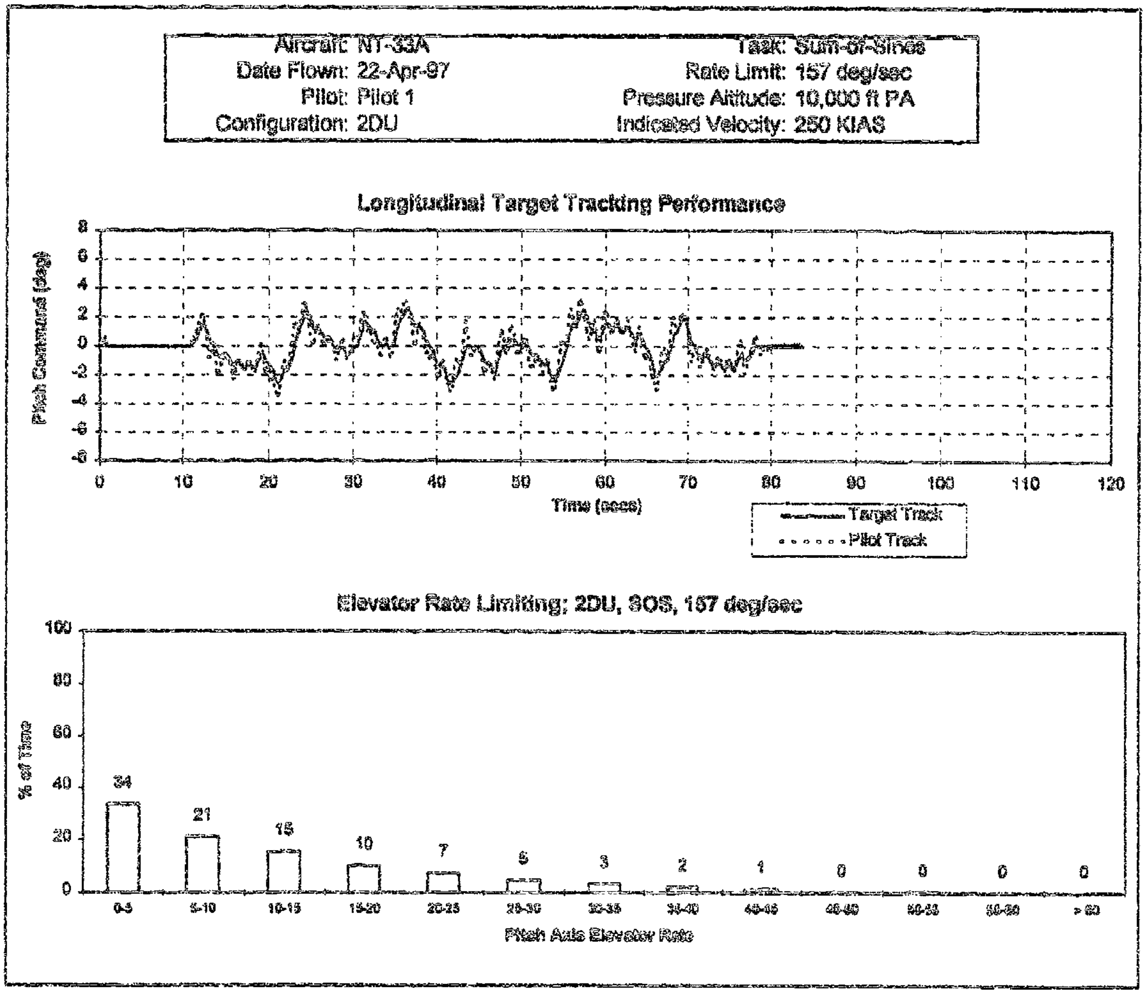

Figure C36 Representative Flight Test Result 2DU, Rate Limit of 157 Degrees Per Second, Sum-of-Sines Task, Pilot 1

Table C73
PILOT COMMENTS FOR 2DU, RATE LIMIT OF 157 DEGREES PER SECOND, SUM-OF-SINES TASK

Aircraft Configuration: 2DU	Rate Limit: 157 degrees per second		Tracking Task: Sum-of-Sines
Pilot - Sortie(s)	Pilot 1 - 9*	Pilot 2 - Not Flown	Pilot 3 - 8
Cooper-Harper Ratings	3	Not Flown	3
PIO Ratings	2	Not Flown	2
AIRCRAFT			
Initial Response	Responsive	N/A	Responsive
Steady-State Response	Responsive +	N/A	Responsive
Predictable	Yes	N/A	Yes
Gross Acquisition	Easy (one to two overshoots)	N/A	Easy
Fine Tracking	Desired	N/A	Desired
PILOT INTERFACE			
Control Harmony	N/A	N/A	N/A
Stick Forces	Low (firm and comfortable)	N/A	Medium
Compensation	Minimal	N/A	Moderate (low end)
Workload	Minimal	N/A	Tolerable (low end)
Was there a PIO? Easily Induced?	No No	N/A	No Yes (undesirable motions)
COMMENTS			
Good Characteristics	Good airplane.	N/A	Overall predictable and good tracker.
Bad Characteristics	Slightly over-responsive in initial capture.	N/A	Two to three oscillations. "Springy" initial response. Mildly unpleasant deficiencies.

Notes: 1. An "*" indicates test point plotted in Figure C36.
2. N/A - not applicable.

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APPENDIX D

DATA PARAMETER LIST

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DATA PARAMETER LIST

GROUND-BASED AND FLIGHT TEST DATA PARAMETERS

The data parameter requirements which were collected for all test points are shown in Table D1.

In support of the four test objectives, the following specific data were collected:

1. For Objective 1, the NT-33A time-history data to generate pitch-step and frequency response for comparison with preflight predictions.

2. For Objective 2, 2D elevator position and rate time-history data of the discrete tracking task for a range of rate limits (Table D2 and Figure D1). Data were collected and analyzed from the USAF TPS simulator and the NT-33A flight test.

3. For Objectives 3 and 4, the pilot comment card, Figure D2, (including Cooper-Harper [Figure D3] and PIO ratings [Figure D4]); the flight test debrief; and the time-history data (Table D3).

The pilot comment card, the Cooper-Harper Rating scale, the PIO Rating scale, the postflight debrief, and the time-history data requirements are contained in this appendix.

DEFINITIONS AND SCALES FOR PILOT COMMENT CARD

Aircraft:

Initial response.

Initial aircraft movement due to control input.

1. "Slow." Initial aircraft movement is not quick enough to accomplish task.

2. "Responsive." Initial aircraft movement is quick enough to accomplish task.

3. "Fast." Initial aircraft movement inhibits accomplishment of task.

Table D1
FLIGHT AND GROUND-BASED SIMULATION TEST PARAMETERS

Data Parameter	LAMARS Ground-Based Simulation	NT-33A Flight Test
Pilot Comment Card	X	X
Cooper-Harper Rating	X	X
PIO Rating	X	X
Flight Test Debrief		X
Time-History Data		X

Note: LAMARS - large amplitude multimode aerospace research simulator

Table D2
HUD TRACKING TASK PERFORMANCE CRITERIA

Task	Desired	Adequate
HUD Tracking Task	Maintain command bar (target) within the 10-millimeter circle of the fixed reference symbol for 50 percent of the time[1]	Maintain command bar within the 20-millimeter circle of the fixed reference symbol for 50 percent of the time[1]

[1] Time includes gross acquisition. Gross acquisition performed aggressively, achieving desired/adequate criteria as quickly as possible.

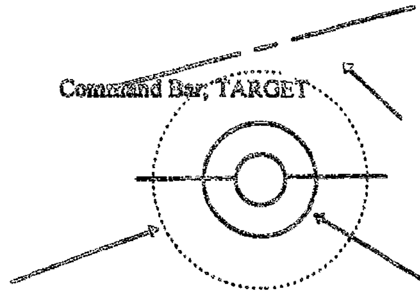

Figure D1 HUD Tracking Task Symbology

Steady-State Response.

Aircraft movement during control displacement.

1. "Slow." Aircraft movement is not quick enough to accomplish task.

2. "Responsive." Aircraft movement is quick enough to accomplish task.

3. "Fast." Aircraft movement inhibits accomplishment of task.

Predictable.

Does aircraft movement begin/cease when desired?

1. "Yes." Aircraft movement begins/ceases when desired.

2. "No." Aircraft movement does not begin/cease when desired.

Gross Acquisition.

Initial acquisition of HUD target.

1. "Easy." Not difficult.

2. "Difficult." Hard to perform.

Fine track.

Fine tracking of HUD target.

1. "Adequate." Target tracked within 10-millimeter circle 50 percent of time.

2. "Desired." Target tracked within 5-millimeter circle 50 percent of time.

Pilot Interface:

Control Harmony.

Pitch and roll inconsistencies with application.

1. "Poor." Inconsistencies impacted accomplishment of task.

2. "Good." Inconsistencies did not impact task.

3. "Excellent." No apparent inconsistencies during task.

Stick Forces.

Stick forces, estimated by the pilot, required to displace aircraft.

1. "Low." 0 to 10 pounds.

2. "Medium." 10 to 25 pounds.

3. "High." 25 to 50 pounds.

Workload.

Physical and mental effort required to accomplish task.

1. "Minimal." Task can be performed with relative ease or low level of effort.

2. "Tolerable." Task workload can be borne or endured.

3. "Intolerable." Task workload cannot be borne or endured.

'AVE LIMITS Sortie #______

<table>
<tr><th>COND</th><th>EXP#</th><th>Pilot: Date:</th></tr>
<tr><td></td><td></td><td>AIRCRAFT:
Initial Response — Slow — Responsive — Fast
Steady State Response — Slow — Responsive — Fast
Predictable — Yes — No
Gross Acquisition — Easy — Difficult
Fine Tracking — Adequate — Desired</td></tr>
<tr><td></td><td></td><td>PILOT INTERFACE:
Control Harmony — Poor — Good — Excellent
Stick Forces — Low — Medium — High
Compensation — Minimal — Moderate — Considerable
Workload — Minimal — Tolerable — Intolerable
Was there a PIO? — Yes — No
Easily Induced? — Yes — No</td></tr>
<tr><td></td><td></td><td>RATING SCALES:
1. Cooper Harper Rating
2. PIO Rating
3. Good Comments
4. Bad Comments</td></tr>
</table>

Figure D2 Pilot Comment Card

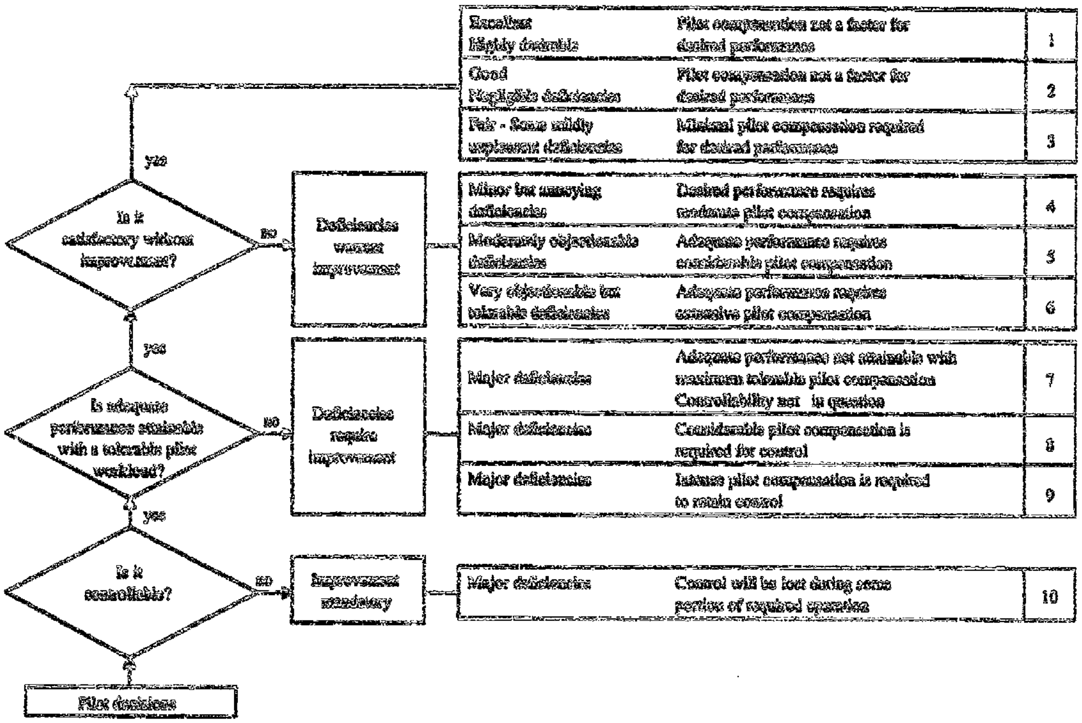

Figure D3 Cooper-Harper Rating Scale (Reference 9)

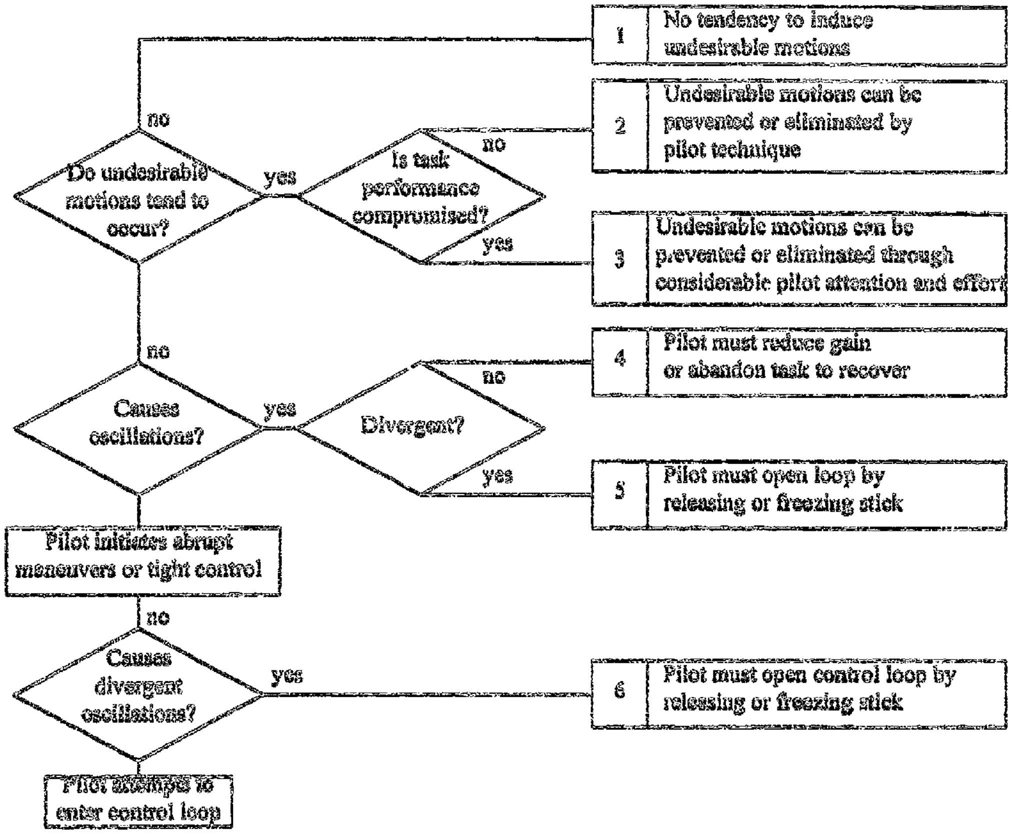

Figure D4 PIO Rating Scale (Reference 9)

Compensation.

Pilot must increase workload to improve aircraft performance due to deficient vehicle characteristics.

1. "Minimal." Task can be performed with relative ease or low level of effort.

2. "Moderate." Task workload can be borne or endured.

3. "Considerable." Task workload cannot be borne or endured.

Was there a PIO?

Uncommanded aircraft oscillations.

1. "Yes." Uncommanded aircraft movement.

a. If Yes, easily induced?

1) "Yes." Uncommanded aircraft movement easily induced.

2) "No." Uncommanded.

2. "No." No uncommanded aircraft movement not easily induced.

Flight Test Debrief:

1. If possible Calspan safety pilot should be present.

2. The flight test debrief should be conducted as soon as possible after completing the sortie. The pilot debrief will always be conducted the same day as the flight.

Table D3
TIME-HISTORY DATA REQUIREMENTS

No.	Name	Symbol	Rate	Unit	Precision	Range
1	time	t	100 Hz	sec	0.010	N/A
2	pitch stick position	δes	100 Hz	in	0.050	±10
3	roll stick position	δas	100 Hz	in	0.050	±10
4	rudder pedal position	δrp	100 Hz	in	0.025	±5
5	lateral acceleration, cg	Ny_{cg}	100 Hz	g	0.025	±5
6	pitch stick force	Fes	100 Hz	lb	0.500	±100
7	roll stick force	Fas	100 Hz	lb	0.250	±50
8	rudder pedal force	Frp	100 Hz	lb	0.500	±100
9	pitch tracking command	θc	43 Hz	deg	0.015	±3
10	pitch tracking error	θerror	43 Hz	deg	0.015	±3
11	pressure altitude	h	100 Hz	ft	10.000	10,000±2,000
12	event marker	evt	100 Hz	N/A	N/A	N/A
13	true airspeed	v_t	100 Hz	ft/sec	5.000	±1000
14	roll rate	p	100 Hz	deg/sec	0.500	±100
15	pitch rate	q	100 Hz	deg/sec	0.250	±50
16	yaw rate	r	100 Hz	deg/sec	0.250	±50
17	normal acceleration at cg	nz_{cg}	100 Hz	g	0.025	±5
18	angle-of-attack	α	100 Hz	deg	0.100	±20
19	sideslip angle	β	100 Hz	deg	0.100	±20
20	sin (pitch angle)	θ	100 Hz	N/A	0.287 deg	±57.3 deg
21	sin (roll angle)	φ	100 Hz	N/A	0.287 deg	±57.3 deg
22	roll command after R.L.	δaca	43 Hz	deg	0.200	±40
23	elevator command before rate limit	δecb	43 Hz	deg	0.200	±40
24	indicated airspeed	v_i	100 Hz	kt	1.375	0.0 - 550
25	elevator command after rate limit	δeca	43 Hz	deg	0.200	±40
26	roll tracking command	φc	43 Hz	deg	0.350	±70
27	roll tracking error	φerror	43 Hz	deg	0.350	±70
28	normal acceleration at pilot station	nz_p	100 Hz	g	0.025	±5
29	actual elevator position	δe	100 Hz	deg	0.020	±4

Note: N/A - not applicable

3. Each test point will be separately debriefed.

4. The HUD video will be reviewed for each test point debrief.

5. The following areas will be addressed and noted during each test point debrief:

a. Did any external factors (traffic calls, turbulence, change in test conditions) bias the results of the test point?

b. After the review of the HUD video, are there further pilot comments concerning aggressiveness?

c. After the review of the HUD video, are there further pilot comments concerning workload?

d. After the review of the HUD video, are there further pilot comments concerning task performance?

e. After the review of the HUD video, are there further pilot comments concerning PIO rating?

f. After the review of the HUD video, are there further pilot comments concerning stick gain?

g. Rate your confidence in the quality of the data collected for this test point (Acceptable, Re-Fly). Reasons for re-fly must be articulated.

h. Further Comments.

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APPENDIX E

REQUIREMENTS TRACEABILITY MATRIX

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REQUIREMENTS TRACEABILITY MATRIX

GENERAL

The requirements traceability matrix details how each test objective was accomplished (Table E1) with specific measure of performance (MOPs) as defined in the test plan for a limited flight test investigation of pilot-induced oscillation due to elevator rate limiting (HAVE LIMITS). The matrix also defines what data requirements were collected for each MOP.

Table E1
REQUIREMENTS TRACEABILITY MATRIX

Objective No.	Objective	MOP No.	MOP	Data Requirements
2.2.1	Verify aircraft configurations	1.1	Compare time and frequency data from the NT-33A against preflight predictions.	Time histories from step inputs and Bode plots from flight test.
2.2.2	Determine three rate limits for use in NT-33A	2.1	Determine three rate limits using the USAF TPS simulator.	Time history of elevator rate.
		2.2	Calspan will determine three recommended rate limits for sortie 1.	Time history of elevator rate and criteria used for choosing rate limits.
		2.3	Verify recommended rate limits giving sufficient results.	Time history of elevator rate.
2.2.3	Gather in-flight data for the test condition matrix in Appendix A	3.1	Pilot comments, CH ratings, PIO ratings, and time histories.	Pilot comments, CH ratings, PIO ratings, and time histories (Table D3).
2.2.4	Gather ground-based simulation data for the same test points flown in 2.2.3	4.1	Pilot comments, CH ratings, and PIO ratings.	Pilot comments, CH ratings, and PIO ratings.

Notes: 1. MOP - measure of performance
2. TPS - Test Pilot School
3. CH - Cooper-Harper
4. PIO - pilot-induced oscillation

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APPENDIX F

DETAILED TEST PROCEDURES

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DETAILED TEST PROCEDURES

GENERAL

In the accomplishment of the limited flight test investigation of pilot-induced oscillation due to elevator rate limiting (HAVE LIMITS) flight test program, the following test procedures were defined and repeated for each test mission. The defined overall test procedures include the pretest briefing, in-flight test procedures, and post-test briefing.

Pretest Briefing:

The USAF TPS HAVE LIMITS test team chaired the pretest briefings before each flight. The test objectives, procedures, success and go/no-go criteria, aircraft status and crewmember responsibilities were discussed. Any data products needed at the end of the flight were also discussed. Go/No-go criteria were reviewed during the pretest briefing. A checklist for the go/no-go criteria is gdefined in Table F1.

In Flight Test Procedures:

The project pilot was in the front cockpit of the NT-33A aircraft, with Calspan safety pilot in the rear cockpit. Each sortie consisted of a 60-second warm-up period, followed by a series of 2-minute HUD tracking tasks. At the completion of each test point, the Calspan safety pilot would program the in-flight simulator for the next test point, while the project pilot voiced his comments, Cooper-Harper rating, and PIO rating for recording on the in-flight voice recorders. The Calspan safety pilot, having completed the changed of test condition, was ready for the next test point. The procedure was repeated until the fuel limit was reached.

In-Flight Communication Plan:

1. Evaluation pilot takes command of aircraft, safety pilot loads next test configuration.
2. Challenge-response the current test point.
3. Clear the area.
4. Call "begin maneuver."
5. Call "test point complete."
6. Both pilots determine if test point should be reaccomplished (if yes, return to step 2).

Table F1
GO/NO-GO CONSIDERATIONS

Failure	Technical No-Go	Safety of Flight No-Go
No data available from the pitch tracking command	X	
No data available from the roll tracking command	X	
No data available from the pitch tracking error	X	
No data available from the roll tracking error	X	
No data available from the elevator command after rate limit	X	
No data available from the elevator command before rate limit	X	
No data available from the pitch stick position	X	
No data available from the simulated elevator	X	
HUD or HUD tracking task not available	X	
Safety trip system (check each flight prior to first point)		X
Variable flight control system	X	
Weather (including severe to extreme turbulence)	X	

7. Evaluation pilot voices his comments and ratings for the in-flight voice recorder.

8. Safety pilot sets the NT-33A aircraft for the next test condition.

9. Cleared to next test point, go to step 1.

10. Safety of Flight "Knock it off."

11. Out of test limits "Terminate."

Post-Test Debriefing:

The USAF TPS HAVE LIMITS test team chaired the post-test briefings after each flight. The briefing included the aircraft status, a review of the objectives, the success criteria associated with those objectives, and any lessons learned. A review of the test points was also accomplished. The HUD video was reviewed prior to the next mission to transfer evaluation pilot comments onto the comment card shown in Appendix D.

LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

Abbreviation	Definition	Unit
A/C	aircraft	---
AFB	Air Force Base	---
AFFTC	Air Force Flight Test Center	---
CAP	control augmentation parameter	---
CH	Cooper-Harper	---
Exp	Calspan-designated experiment numbers	---
FOV	field of view	---
FRA	frequency response analysis	---
F_s	Stick Force	lb
HUD	head-up display	---
IAW	in accordance with	---
LAMARS	large amplitude multimode aerospace research simulator	---
LOES	lower order equivalent system	---
MIL-STD	military standard	---
N/A	not applicable	---
PIO	pilot-induced oscillation	---
PIOR	pilot-induced oscillation rating	---
SOS	sum-of-sines	---
RL	elevator rate limit	deg/sec
TPS	Test Pilot School	---
USAF	United States Air Force	---
VSS	variable stability system	---
ζ_{sp}	short-period damping	---
$\omega_{n\,sp}$	short-period natural frequency	Hz
$T_{\theta 2}$	high frequency pitch attitude zero	Hz

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